

MEASUREMENT OF THE LUMBAR SPINAL CANAL BY
DIAGNOSTIC ULTRASOUND

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DECLARATION

This thesis is based on work carried out in the past
three years.

It was written by myself and the concepts are my
own.

* * * * *

ACKNOWLEDGEMENTS

I am grateful to a number of people who have made this thesis possible.

For the co-operation of Dr. David Ottewell in helping to identify the ultrasonic echoes; to Miss Margaret Wicks, Mrs. Catherine Hibbert and Miss Pamela Wellman for scanning many hundreds of patients; to Dr. Ali Chalabi for recording anthropometric data; to Mr. G. Swann for his photographs and assistance constructing the photographic box; to Mr. J.H.S. Scott for his advice and encouragement; to Mrs. Jean Reynolds for her secretarial assistance, and for the tolerance of my wife and family.

* * * * *

"O LORD, grant me the serenity to accept the things I cannot change; the courage to change the things I can; and the wisdom to know the difference."

	<u>TABLE OF CONTENTS</u>	<u>PAGE</u>
Summary		7
Part I.	<u>Measurement of the Lumbar Spinal Canal in Vivo</u>	8
	Section 1. Limitations of conventional methods.	9
	Section 2. Spinal Canal Measurement by Diagnostic Ultrasound.	11
	Section 3. Theoretical consideration of the A-Scan.	18
	Section 4. Repeatability.	25
	Section 5. The Origin of the Spinal Echoes.	30
	Section 6. Safety of Ultrasound.	38
Part 2.	<u>Ultrasound Measurements of the Lumbar Spinal Canal in over Seven Hundred randomly selected subjects from a South Yorkshire population.</u>	40
	Section 7. Measurements from young adults (15-21 years).	41
	Section 8. Measurements from children (2-18 years).	43
	Section 9. Measurements from three occupational groups between 50 and 65 years.	47
	Section 10. Right and left sides.	52
Part 3.	<u>Anthropometric Measurements</u>	53
	Section 11. Comparison between Anthropometric measurements and canal size in one hundred young men.	54
Part 4.	<u>Direct Measurements of the Lumbar Spinal Canal from Skeletons</u>	72
	Section 12. Measurement from three skeletal populations.	73

	<u>PAGE</u>
Part 5. <u>Ultrasound Measurements of the Lumbar Spinal Canal in over Seven Hundred Patients with Back and/or Leg Pain.</u>	95
Section 13. Measurements from patients with disc lesions.	96
Section 14. Measurements from patients with Root Entrapment Syndrome.	102
Section 15. Measurements from Patients with symptoms of neurogenic claudication.	107
Section 16. Measurements from Patients with spondylolisthesis.	117
Section 17. Measurements from Patients attending a Back Pain Clinic.	122
 Part 6. <u>The Application of Ultrasound Measurement of the Lumbar Spinal Canal.</u>	 126
Section 18. Clinical Application.	127
Section 19. Prevention of Back Pain.	130
 REFERENCES	 134
 PUBLICATIONS	 143

ABSTRACT OF THESIS

Name of Candidate Richard William PORTER
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Title of Thesis Measurement of the Lumbar Spinal Canal by Diagnostic
 Ultrasound.

* * * * *

It is difficult to measure the lumbar spinal canal by conventional methods. A technique is described using diagnostic ultrasound to measure a fifteen degree oblique sagittal diameter. Reasons are presented that the reflecting surfaces are the bony margins of the canal. Right and left sides of the canal are measured at each lumbar level. The mean inter-observer error is .52 mm. at L.5.

Measurements were obtained from groups of volunteers between the ages of two and sixty-five years. In each group, the mean measurements were widest at L.1, becoming narrower towards L.4, and widening again at L.5. The canal tended to be widest in the late teens. The measurements were less in later life, being age-related and not occupation-related. The canal was relatively wide in children.

Anthropometric measurements were recorded from one hundred young mining recruits and compared with canal size. No single measurement showed a correlation higher than .27. Multiple regression analysis was applied combining a maximum of three measurements. Subjects with small canals tended to have a small skull lateral measurement, small lower limbs, disproportionate forearm and upper arm measurements and lower limb inequality. Correlations also suggest that factors which affect lower limb inequality may affect the development of the canal's trefoil shape.

Vertebrae from two archaeological populations and a twentieth century collection were examined photographically, to record the shape and size of the spinal canal. The same general trends were present in each population. The fifteen degree oblique diameter tended to be equal or less at L.5 than L.4 in the most trefoil spines. The trefoil shape was correlated with other vertebral measurements. Factors responsible for the lumbo-sacral angle may affect the canal shape.

Ultrasound measurements of the canal were obtained from patients with back and/or leg pain, with a diagnosis of lower lumbar disc lesion, root entrapment syndrome, neurogenic claudication or spondylolisthesis. Many patients had very narrow canals. It is suggested that symptoms are frequently associated with the contents of a small and sometimes trefoil canal being compromised by a precipitating lesion.

Ultrasound provides a simple, safe and accurate method of measuring the central spinal canal. It is presented as a useful clinical investigation for patients with back pain. It also offers an opportunity to prevent back pain, by identifying in early life, subjects at risk.

* * * * *

PART I

MEASUREMENT OF THE LUMBAR SPINAL CANAL IN VIVO

PART 1. Section 1

LIMITATIONS OF CONVENTIONAL MEASUREMENT

Accurate measurement of the lumbar spinal canal from conventional x-rays is difficult because the canal boundaries are frequently indistinct, especially the posterior boundary at the lower lumbar levels. Jones and Thomson (1968) and Eisenstein (1977) have described methods of measuring the mid sagittal diameter from lateral x-rays but this is not always easy in practice, (Christenson 1977). The interpedicular diameter is more readily measured from an anteroposterior x-ray but apart from the diagnosis of spinal tumour (Haworth and Keillor 1962), this diameter has not been found to be of clinical significance (Verbiest 1955).

Transverse axial tomography can demonstrate bony encroachment into the canal, (Gargano et al 1974). Computerised Axial Tomography can identify the shape of the canal (Sheldon et al 1977, Kreel and Osborn 1976) and permit measurement (Colley and Dunsker 1978), (Postacchini et al 1980).

Metrizamide radiculography is perhaps the best method of demonstrating the restraint that the canal places upon its contents. The limitations of myelography are well documented, Jacobson (1976), McIvor and Kirkaldy Willis (1976), Ehni (1969), Choudhury and Taylor (1976). The demonstration of an apparently adequate mid sagittal and interpedicular diameter does not exclude marked reduction in cross sectional area from

PART I. Section I. a trefoil shaped canal.

Radiculography can also be technically difficult in the presence of a narrow canal and can be painful for the patient (Williams 1975). Bestawros et al (1979) state that epidural venography can also demonstrate spinal stenosis.

Verbiest (1955) designed a "stenosimeter" to measure the mid sagittal diameter of the lumbar canal at operation, and Rothman and Simeone (1975) state that the canal can be measured accurately only by direct means. Even with direct measurement at operative exposure, however, the errors may be considerable.

PART I. Section 2. SPINAL CANAL MEASUREMENT BY DIAGNOSTIC
ULTRASOUND

Ultrasound has been used for over a decade in obstetric diagnosis and more recently in the investigation of abdominal structures, the urinary tract, the eye and the heart, (Lunt 1978). It had been thought, however, that the ability of bone to absorb ultrasound would prevent any meaningful echoes being recognised from within the spinal canal.

Technique

Using a Nuclear Enterprises Ltd. Dasonograph NE 4200 (Fig. 1), a fifteen degree oblique sagittal diameter of the lumbar spinal canal has been measured by pulsed ultrasound.

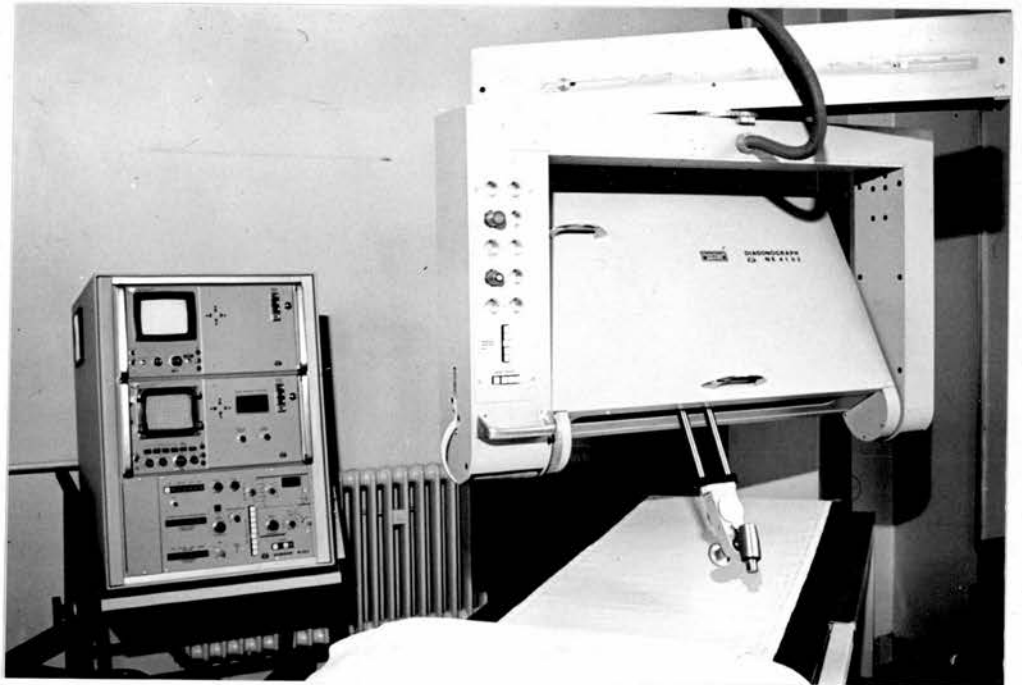


FIG. 1. DIASONOGRAPH, NUCLEAR ENTERPRISES LTD. 4200

PART I. Section 2. Olive oil is used as a coupling medium between the transducer and the skin. A 1.5 megahertz transducer is placed one centimeter from the mid line of the lumbar spine, inclined at an angle of fifteen degrees to the sagittal plane, and moved longitudinally at the same inclination from the first to the fifth lumbar level, (Fig. 2).



FIG. 2. 1.5 MEGAHERTZ TRANSDUCER SCANNING THE LUMBAR SPINE

With repeated movements and slight alteration of the transducer's lateral position, it is possible to recognise echoes on the B-Scan reflected from the surfaces of the laminae and from the posterior surface of the vertebral bodies, (Fig. 3). If these echoes are not immediately demonstrated, the gantry is moved slightly more laterally or medially until the particular pattern of echoes is obtained.

PART I. Section 2.



FIG. 3. ECHOES FROM A B-SCAN

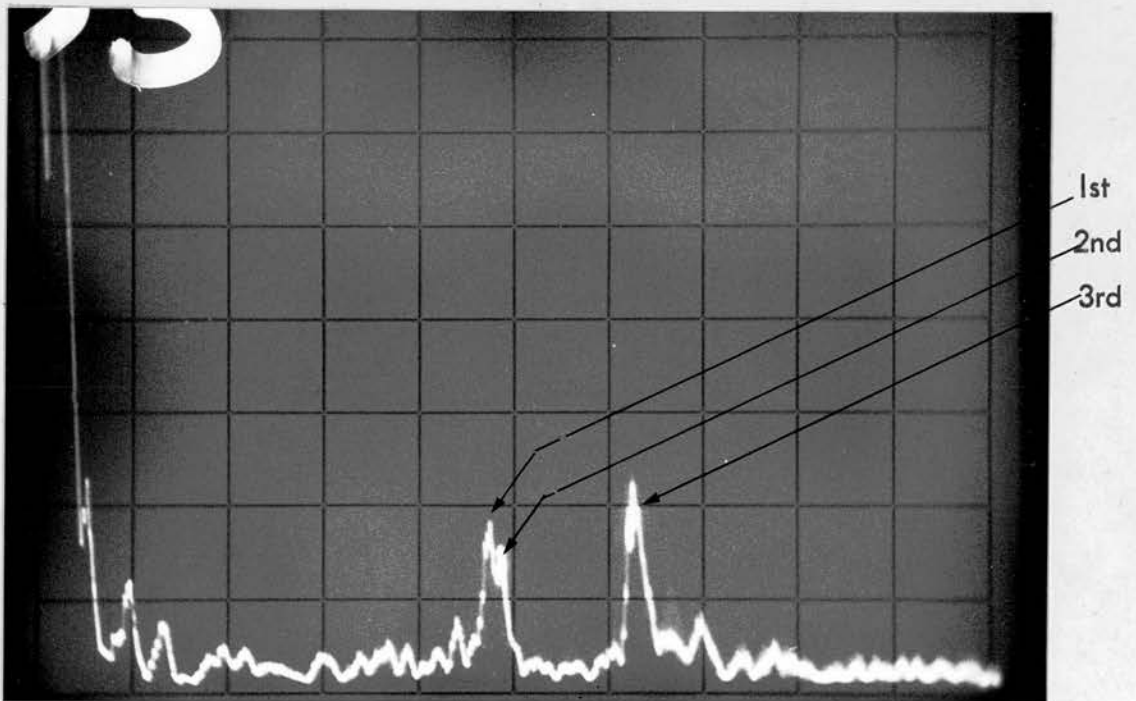


FIG. 4. ECHOES FROM AN A-SCAN.

PART I. Section 2. The Diasonograph permits a simultaneous A-Scan display (Fig. 4). Three major echoes are demonstrated on the A-Scan at each vertebral level, from the posterior and anterior surfaces of the laminae and from the posterior surface of the vertebral body, (Fig. 5).

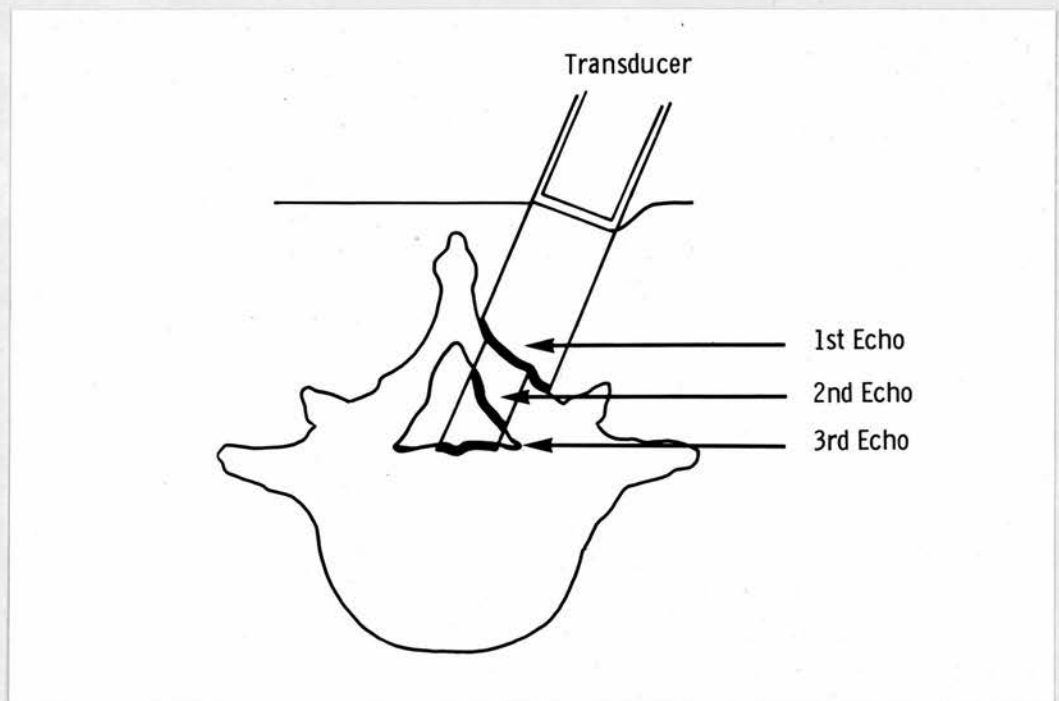


FIG. 5 DIAGRAM TO SHOW REFLECTING SURFACES OF THE THREE ECHOES .

These echoes are maximised by slight alteration of the transducer's position, and spurious echoes removed by electronic filtering. The echo amplitudes are a direct function of time, which itself is related to the distance of the reflecting surfaces from the transducer. The time interval between the second and third echoes from the canal boundaries is related to the distance between the reflecting surfaces. It is measurable in millimeters on a digital read-out, calibrating

PART I. Section 2. the speed of sound in soft tissues at 1538 m/sec.

The measurement is facilitated by electronic calipers. They are first positioned on the B-Scan at the site of the particular echoes which are believed to be reflected from the canal boundaries. The calipers are simultaneously displayed on the A-Scan, and with fine adjustment placed at the apex of the second and third echoes.

The vertebral level being measured is identified on the B-Scan by recognising the sacrum. The sacral lamina provides a continuous band of echoes (Fig. 6) and the lumbo-sacral angle is apparent.

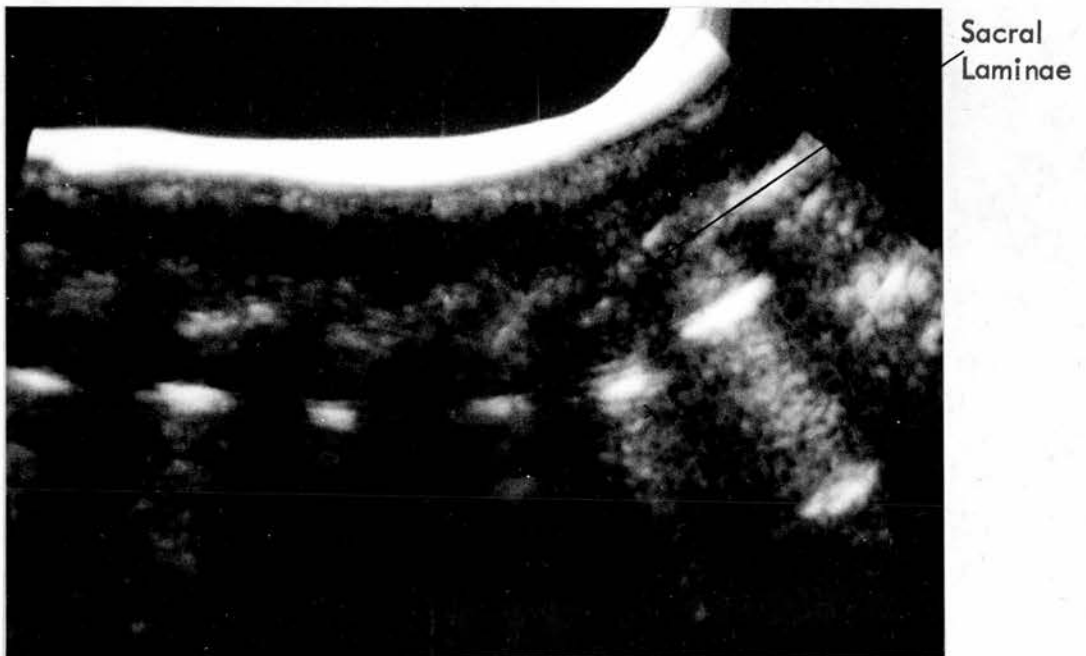


FIG. 6. B-SCAN SHOWING THE LUMBO-SACRAL ANGLE AND ECHOES FROM THE SACRAL LAMINA

PART I. Section 2. The wide and the narrow canal can be readily recognised from the B-Scan (Figs. 7 and 8), but measurements are recorded from the A-Scan, between the calipers placed at the apex of the second and third echoes. Right and left sides of the canal are measured at each lumbar level.

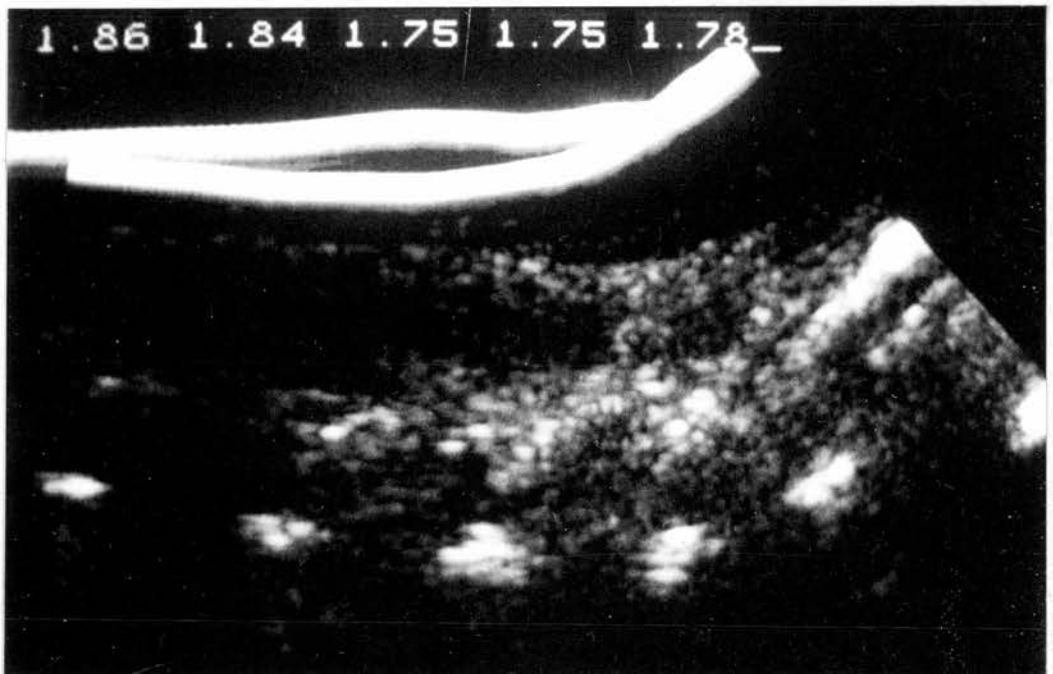


FIG. 7. B-SCAN SHOWING WIDE CANAL

PART I. Section 2.

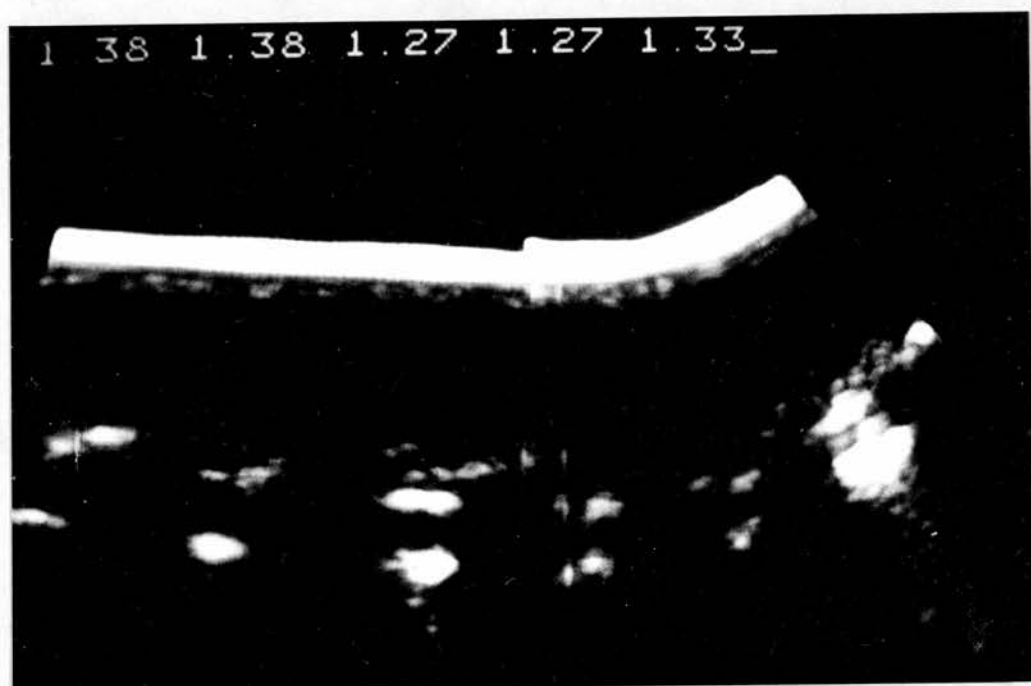


FIG. 8. B-SCAN SHOWING NARROW CANAL

PART I. Section 3. THEORETICAL CONSIDERATION OF THE A-SCAN

Ultrasound is reflected from the boundaries of tissues of different density. This is particularly marked at the interface between bone and soft tissue. The magnitude of the echo depends greatly on the relative acoustic impedance of the tissue at each side of the interface. The acoustic impedance for compact bone is $6.12 \times 10^6 \text{Ns/m}^3$. For ligament it is $1.63 \times 10^6 \text{Ns/m}^3$ and for cerebro-spinal fluid, $1.51 \times 10^6 \text{Ns/m}^3$. The echoes from a bony-soft tissue interface can therefore be expected to be much stronger than from adjacent soft tissue boundaries. The magnitude of the three echoes on the A-Scan supports their being reflections from a bony interface.

It is not necessary for the macroscopic surface of the boundary to be normal to the transducer for the echoes to be received. The microscopic irregularity of the bony surface ensures that some part of the bony interface is normal to the transducer, and although much of the sound may be scattered, transmitted or absorbed, some is reflected and received by the transducer, (Fig. 9).

PART I. Section 3.

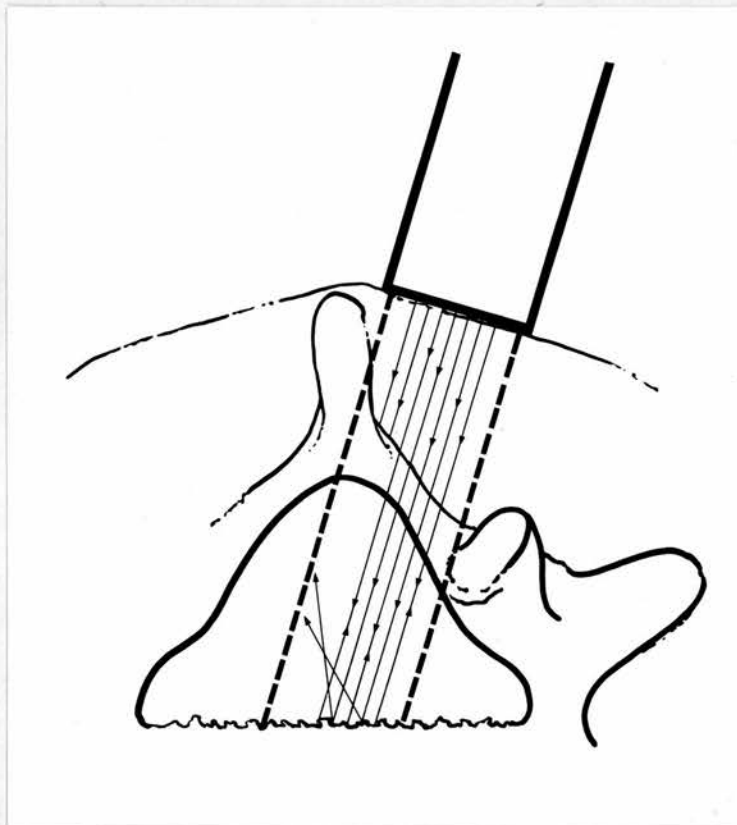


FIG. 9. DIAGRAM SHOWING THAT SOME SOUND IS REFLECTED NORMAL TO THE TRANSDUCER, FROM AN IRREGULAR SURFACE.

It is believed that the three major echoes reflected from the bony surfaces, are from the posterior surface of the lamina, the anterior surface of the lamina, and from the posterior surface of the vertebral body.

The first echo from the posterior lamina surface is reflected from a large area of bone, and the amplitude of the echo may be expected to be large. This may be amplified by the concave nature of the surface focusing rather than diverging the sound.

PART 1. Section 3. The second echo is reflected from a much smaller area of the anterior surface of the lamina. The part of the lamina through which sound is transmitted must be sufficiently thin to permit the transmission of ultrasound into the spinal canal and its return. It is described as the "window". This "window" will vary from one vertebra to another. The area of bone reflecting sound will be smaller on the anterior than the posterior surface of the lamina and it would be expected to produce an echo of smaller amplitude. The speed of sound in bone is two and a half times faster than in soft tissues (Wells 1969). Therefore, when observing the echoes on the A-Scan, the first and second echoes are disproportionately close together. The two echoes are frequently within the same complex. The smaller amplitude of the second echo is recognised on the declining face of the first echo (Fig. 4).

The third echo from the posterior surface of the vertebral body is the most easily recognised of the three echoes, perhaps because it is the only echo from that depth below the surface of such large amplitude.

PART I. Section 3

In attempting to understand what part of the reflecting surface is represented in the apex of the echo, it is helpful to represent the beam of ultrasound in a two dimensional diagram, (Fig.10).

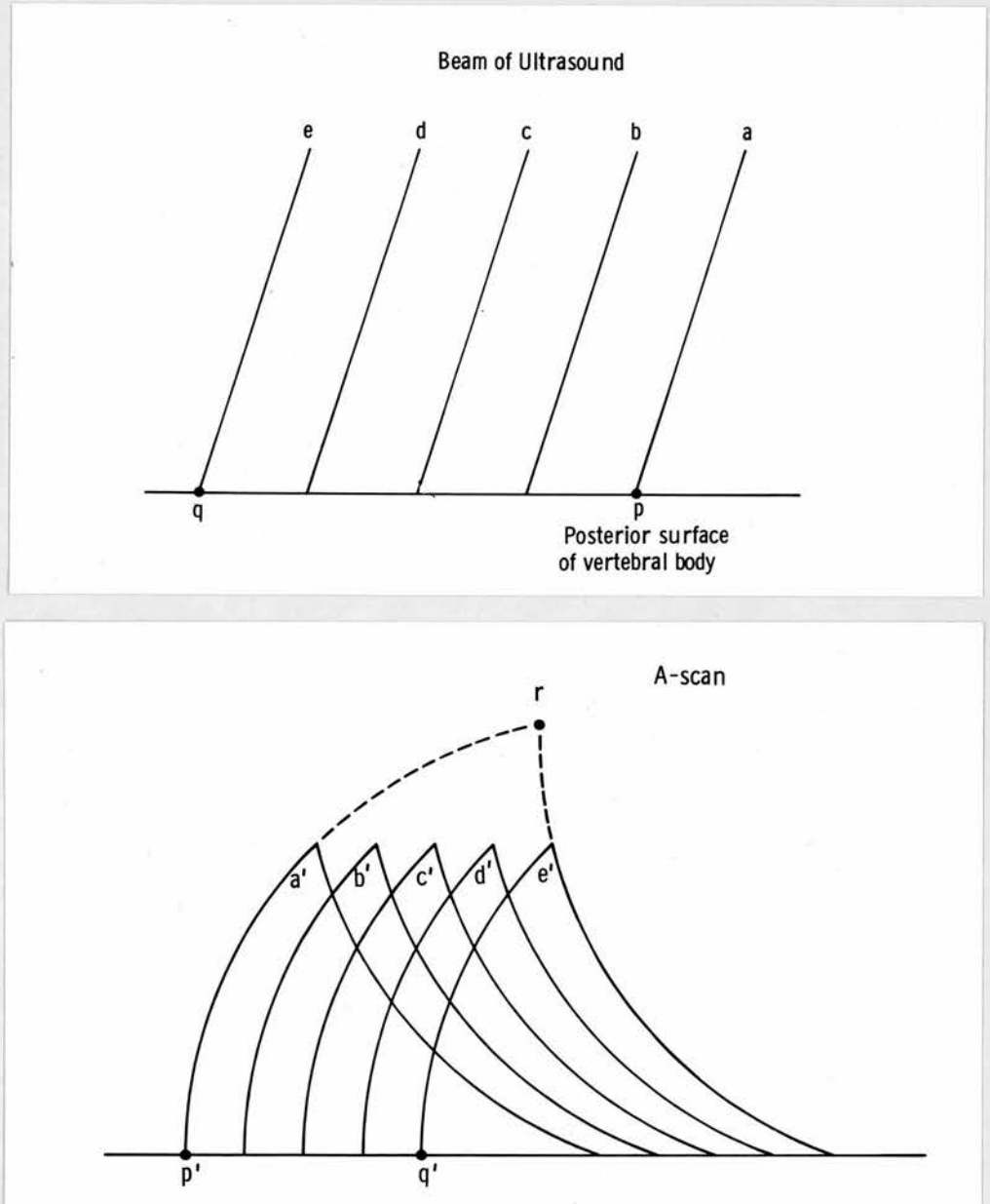


FIG.10 DIAGRAM TO SHOW COMPOSITION OF THE
A-SCAN IN RELATION TO THE ULTRASOUND BEAM.

The first part of the ultrasound beam (a) to be reflected and received by the transducer is represented on the A-Scan in an exponential wave form (a'). The second part (b) is represented as (b'), and (c) (d) (e) as (c') (d') (e').

PART I. Section 3

The point (p') where the first part of the echo leaves the base line represents sound reflected from the point (p) on the posterior surface of the vertebral body, and (q') represents the point (q), but it is not possible to identify the point on the bony surface represented by the apex of the composite echo (r). The apex of the echo (r) represents 'some point' on the posterior surface of the vertebral body between (p) and (q). It is probably closer to (q) than (p).

Measurements are made between the apex of the second and the apex of the third echo, because these are readily identifiable. They are not recorded from the point on the A-Scan where the echo leaves the base line because this point is usually obscured by other echoes.

The increase in the speed of sound through bone does not affect the measurement because the sound of both second and third echoes passes through the same lamina twice.

The beam of ultrasound has been shown diagrammatically in two dimensional form and in parallel. The beam is, however, three dimensional, and it is not parallel. The sound first converges and then diverges, (Fig. II).

PART I. Section 3.

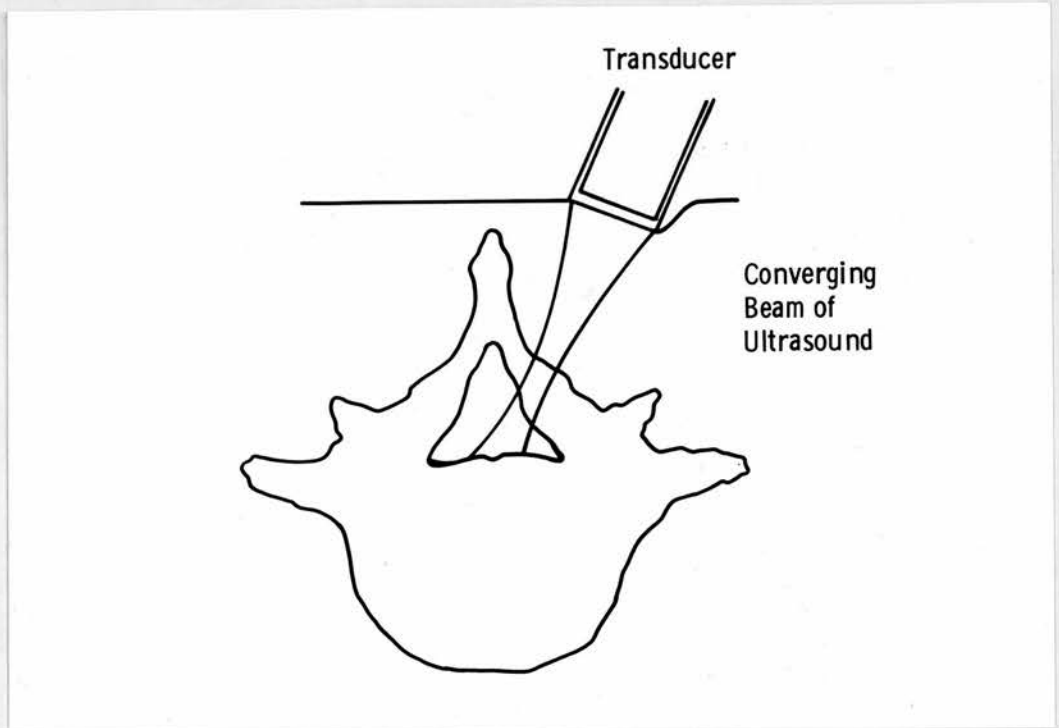


FIG. 11. DIAGRAM TO SHOW THAT THE BEAM OF
ULTRASOUND IS NOT PARALLEL, BUT IT CONVERGES
AND THEN DIVERGES.

The 1.5 megahertz transducer used for these measurements is not focussed but the ultrasound beam converges at a depth of 4 cm. which is the approximate depth of the lamina below the skin in an adult.

PART I. Section 3. Conclusions

The echoes recorded on the A-Scan are complex echoes of a three dimensional beam of sound reflected from an oblique surface, and little can be stated about the apex of the echoes except that it represents 'some point' on the reflecting surfaces. The apex of the echo is, however, theoretically constant and repeatable, and it has been found to be highly repeatable in practice.

PART I. Section 4

REPEATABILITY OF ULTRASOUND MEASUREMENT

The repeatability of canal measurement by ultrasound was assessed by two examiners independently, measuring thirty mining recruits between fifteen and eighteen years of age. The mean difference at the five lumbar levels is recorded in Table I.

TABLE I. INTER OBSERVER ERROR (mm) for 30 SUBJECTS

	Mean	S.D.
L.1	.34	.24
L.2	.35	.28
L.3	.37	.35
L.4	.36	.34
L.5	.52	.35

The high degree of repeatability is probably explained by the lamina "window" being completely covered by ultrasound. The periphery of the ultrasound beam is absorbed by the thickened bone: the central part of the beam penetrates the "window" of thin lamina. If it is completely covered by sound, the amount of ultrasound energy entering and being reflected back through the "window" will remain constant. Provided the angle of the transducer remains constant at 15 degrees, the second and third echoes will also remain constant.

PART I. Section 4 Measurement will be repeatable provided the echoes are correctly identified.

The degree of repeatability is dependent upon:

the physical properties of the ultrasound

the obliquity of the transducer in the sagittal plane

the observer's ability to recognise the echoes

and the accurate positioning of the electronic calipers.

PART I. Section 4

It is difficult to explain the reproducibility of measurements from the physical properties of ultrasound, because the echoes are of complex origin from the interface between bone and soft tissue. In addition, the resolution limit of an instrument depends both upon the lateral resolution and range resolution. These in turn depend upon the shape of the echo pulse, the characteristics of the receiver and the precise scattering-reflection process.

The velocity of sound in cerebro-spinal fluid at 37°C . is 1538 m/s. The wavelength for 1.5 megahertz energy is therefore 1.02 mm. One can generally measure in half wave length increments and the minimum increment of measurement in cerebro-spinal fluid will be 0.5 mm. This is compatible with the clinical repeatability of 0.34 ± 0.24 at L.I (Table I).

PART I. Section 4

Cadaveric Measurements

Spines were donated by relatives of two patients who died, and had previously had the spinal canal measured by ultrasound. The lumbar vertebrae were disarticulated, the soft tissue removed, and the fifteen degree oblique sagittal diameter measured using the photographic box later described in Section II. The ultrasound in vivo measurements are compared with the cadaveric measurements in Table 2.

TABLE 2. ULTRASOUND AND CADAVERIC MEASUREMENTS
TWO SPECIMENS

Specimen 1.

	L.1	L.2	L.3	L.4	L.5
Ultrasound R. measurements L.	1.49 1.53	1.47 1.52	1.44 1.45	1.60 1.61	1.44 1.41
Cadaveric R. measurements L.	1.40 1.41	1.42 1.45	1.43 1.43	1.68 1.68	Specimen damaged

Specimen 2.

	L.1	L.2	L.3	L.4	L.5
Ultrasound L. measurements	1.68	1.67	1.64	1.56	1.54
Cadaveric L. measurements	1.62	1.52	1.60	1.40	1.48

PART 1. Section 4

The ultrasound measurement records some measurement in the fifteen degree oblique sagittal plane, but not necessarily to the mid point of the posterior surface of the vertebral body.(Fig.5) Likewise in the sagittal plane the cadaveric measurement recorded by photograph is to the cranial aspect of the posterior surface of the body, which is not necessarily the reflecting surface of the ultrasound echo (Fig.17 Section 5).

Apart from Specimen Two at L.2 and L.4, the ultrasound and cadaveric measurements agreed within one millimeter. In Specimen One, both measurements widened at L.4.

These measurements are compatible with the origin of the echoes being as suggested in the following section.

PART I. Section 5

ORIGIN OF THE ECHOES

It could be suggested that the echoes that are reflected from within the spinal canal have not, in fact, been transmitted through the lamina but through the ligamentum flavum in the interlaminar area. It is believed that some sound is transmitted through the ligamentum flavum, but some also through the lamina, because:

- 1) The laminar and vertebral echoes are in the same vertical plane on the B-Scan, and are not staggered (Fig.12).



FIG. 12. B-SCAN SHOWING THAT THE ECHOES ATTRIBUTED TO THE VERTEBRAE AND LAMINAE TEND TO BE IN THE SAME VERTICAL PLANE, AND NOT STAGGERED.

PART I. Section 5

The echoes which are attributed to the lamina are clearly from a bony surface. They are recorded approximately four centimeters from the skin surface, and are of greater amplitude than other echoes in the same field which are attributed to soft tissue. The echoes attributed to the vertebral body are frequently broader than the laminar echoes and some of the sound may in fact have entered the canal through the inter-laminar area, but it would be difficult to explain the pattern of echoes on the B-Scan unless it is accepted that some sound penetrates the lamina "window".

- 2) Some patients with spinal stenosis have overlapping laminae (Schatzker and Pennal 1968) which make even lumbar puncture difficult, (Williams 1975). The spines of over 3000 Subjects have been measured by ultrasound and difficulty encountered in obtaining echoes only from the very obese and from patients who have had previous posterior spinal fusions. Difficulty has not been experienced in patients with spinal stenosis. Flexing the lumbar spine to increase the interlaminar space does not affect the ultrasound echoes.

PART 1. Section 5

3) Typical B-Scan displays have been obtained from patients with Ankylosing Spondylitis.

4) In spondylolitic spondylolisthesis of the fifth lumbar vertebra, the lamina of L.5 is left behind as the body slips forwards. This widening of the canal at L.5 is clearly demonstrated (Fig. 13), again supporting the echoes being from the lamina and vertebral bodies.

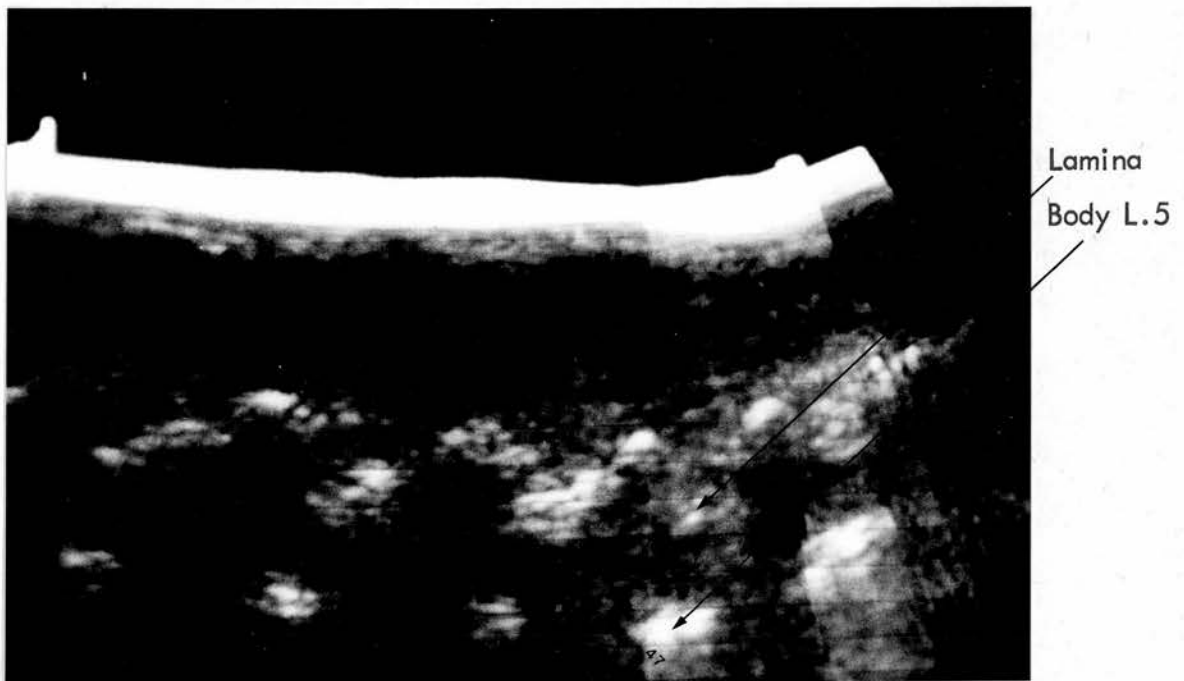


FIG. 13. B-SCAN OF PATIENT WITH SPONDYLOLISTHESIS L5/S1

PART I. Section 5

- 5) If it is suggested that the beam of ultrasound is being transmitted into the canal through the ligamentum flavum in the interlaminar region, then the echoes that have thus far been attributed to the vertebral bodies are, in fact, echoes from the intervertebral disc. These particular echoes have been carefully observed in patients with a known large unilateral lumbar disc herniation demonstrated by radiculography. No unilateral difference in the echo pattern was observed however.

The mean difference in the right and left canal measurements of 70 patients with lower lumbar disc lesions (patients recorded in Section 13) is shown in Table 3.

TABLE 3. ASYMMETRY OF SPINAL CANAL (cm)

	100 Mining Recruits 15-21 yrs of age.		330 men and women 50-65 yrs of age.		70 patients with disc symptoms.	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
L.1	.013	.012	.019	.021	.023	.024
L.2	.014	.013	.021	.026	.032	.041
L.3	.013	.013	.018	.018	.029	.027
L.4	.011	.011	.019	.020	.029	.032
L.5	.015	.015	.018	.022	.024	.021

PART 1. Section 5. The asymmetry is greater in 70 patients with disc symptoms than in 430 asymptomatic subjects, but it is greater at each lumbar level, not only L.4 or L.5. If the echoes were from the intervertebral disc, the asymmetry would be expected at the lower two lumbar levels only.

An intervertebral disc was excised from the articulated cadaveric specimen, without affecting the B-scan display.

- 6) Cadaveric articulated lumbar vertebrae were positioned in a water bath, and a pattern of echoes obtained similar to those from the B-Scan of patients. Pieces of plasticine 3mm x 3mm x 1.5mm were placed over the lamina in an attempt to alter the A-Scan display. The intensity of the third echo was affected most significantly when the plasticine was placed over the cranial part of the lamina. It is assumed that this is the site of the lamina "window" and that the first and second echoes are reflected from this area, (Figs. 14, 15 and 16).

PART 1. Section 5.



FIG. 14 PLASTICINE DISC PLACED OVER CRANIAL ASPECT
OF THE LAMINA AT L.3, IN A WATER BATH.

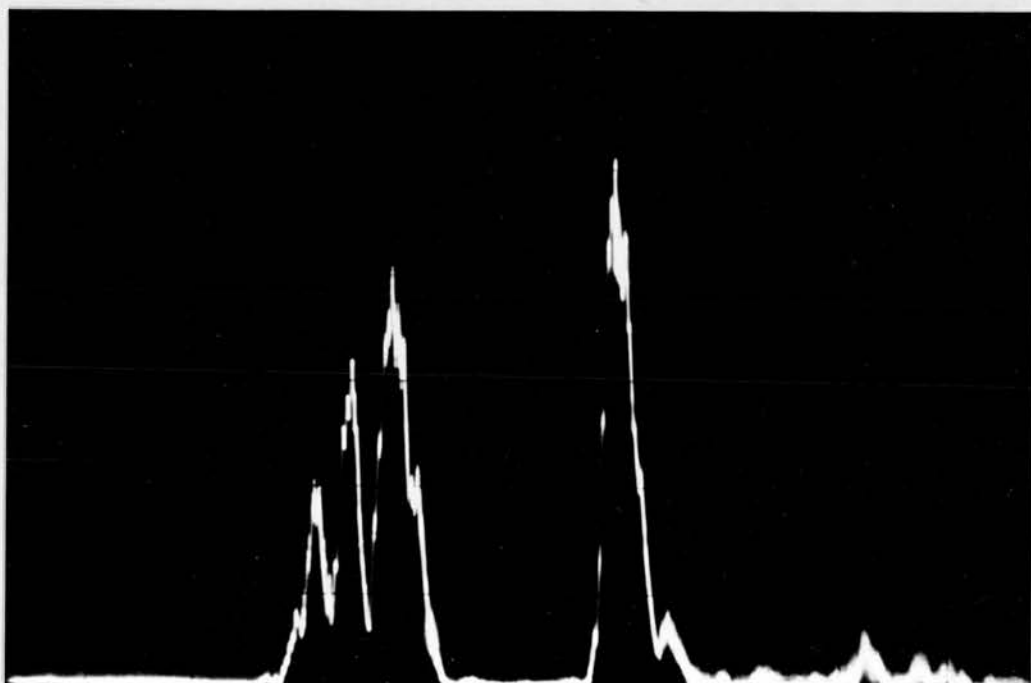


FIG. 15. A-SCAN DISPLAY FROM L.3 IN A WATER BATH
WITHOUT THE PLASTICINE DISC.

PART 1. Section 5

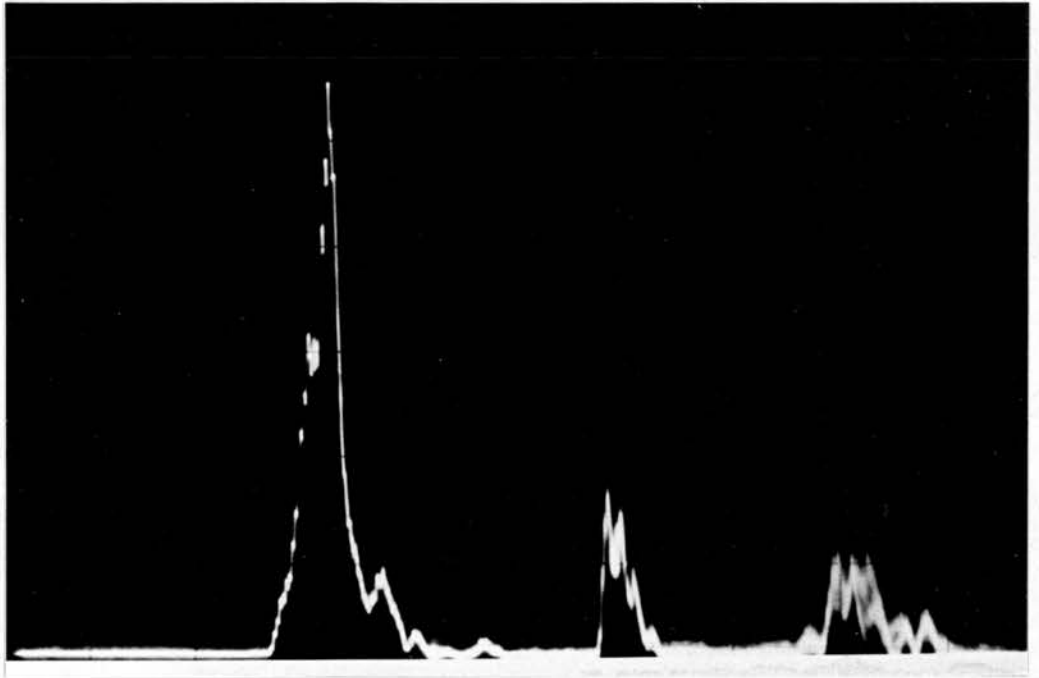


FIG.16. A-SCAN DISPLAY FROM L.3 IN A WATER BATH
WITH THE CRANIAL ASPECT OF THE LAMINA COVERED
BY PLASTICINE (FIG.14).

The fact that the third echo was still present, however, suggested that some sound was reflected from within the canal entering through the ligamentum flavum.

PART 1. Section 5 Conclusions

Some sound is transmitted into the canal through a "window" of vertebral lamina at the cranial part of the lamina, and some sound is also transmitted through the ligamentum flavum into the inter-laminar region (Fig. 17). The echoes from within the canal are not reflected from the intervertebral disc but from the central part of the posterior surface of the vertebral body.

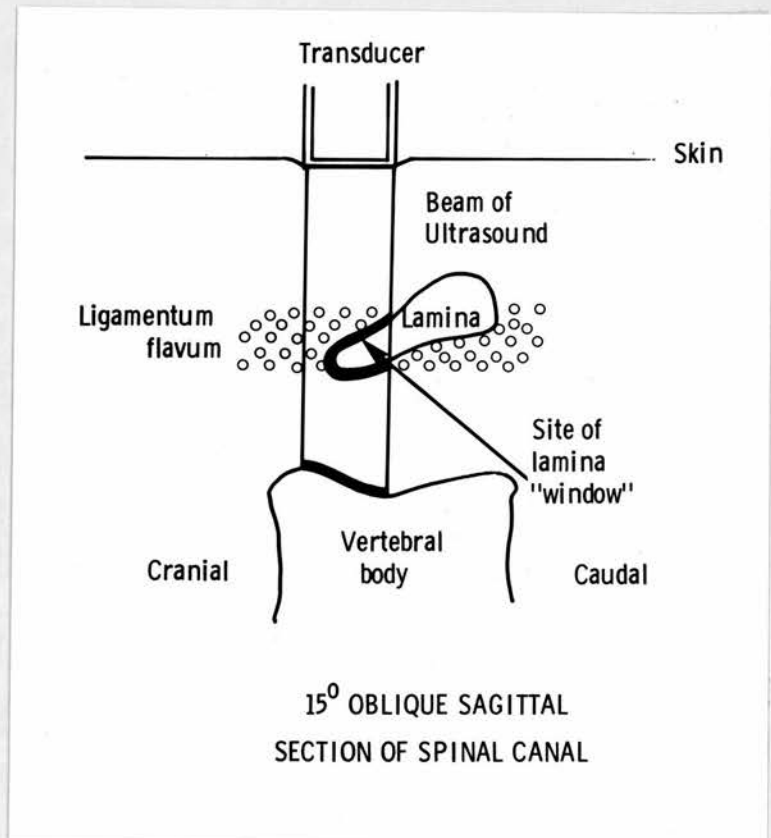


FIG. 17. DIAGRAM TO SHOW THE REFLECTING SURFACES
OF THE THREE ECHOES IN THE 15° OBLIQUE
SAGITTAL PLANE.

PART I. Section 6

SAFETY OF ULTRASOUND

Ultrasound, used at the intensity and for the time required by diagnostic instruments, has not been found to harm biological tissues. Certain effects have been recorded on biological tissues but only when intensity and exposure time is greatly in excess of diagnostic levels.

A temperature rise of 10°C . per second has been produced in small tissue volumes by a strongly focused beam (Hill, 1968), but pulsed echo techniques operated as high as $250\text{W}/\text{cm}^2$ show no significant thermal effects, and this is one hundred times greater than the clinical dose.

Cellular cavitation can occur when microbubbles grow in the cell, during the negative pressure phase of the sound wave. The bubbles can exhibit mechanical resonance, and lead to localised areas of high shear and stress, sufficient to break intra-cellular structures. This has been recorded when the intensity exceeds $2,000\text{ W}/\text{cm}^2$, (Fry 1970). This is more than one thousand time greater than clinical values. Cavitation may be completely absent with the very short pulse lengths, normally used in pulsed echo diagnostic techniques.

PART I. Section 6

Theoretically, ultrasound could disrupt macromolecules and damage chromosomes as a result of direct tissue movement in the transmitting medium. Chemical reactions could be induced or accelerated. No such changes have been recorded however at intensity/duration levels far in excess of diagnostic ultrasound (Baker and Dalrymple 1978).

There is no evidence to suggest that diagnostic ultrasound exposure at levels used clinically produces damage to biological tissues.

PART 2

ULTRASOUND MEASUREMENTS OF THE LUMBAR SPINAL
CANAL IN OVER SEVEN HUNDRED RANDOMLY SELECTED
SUBJECTS FROM A SOUTH YORKSHIRE POPULATION.

PART 2. Section 7 ULTRASOUND MEASUREMENTS OF THE LUMBAR SPINAL CANAL FROM YOUNG ADULTS (15-21 YEARS OF AGE).

Measurements were obtained by ultrasound from two groups of young people between fifteen and twenty-one years of age. The first were 188 unselected male recruits to the coal mining industry in South Yorkshire. The second were 102 unselected female nurses in training at Doncaster Royal Infirmary. The percentiles of canal size at each vertebral level for the two groups are recorded in Table 4 and shown diagrammatically in Fig. 18.

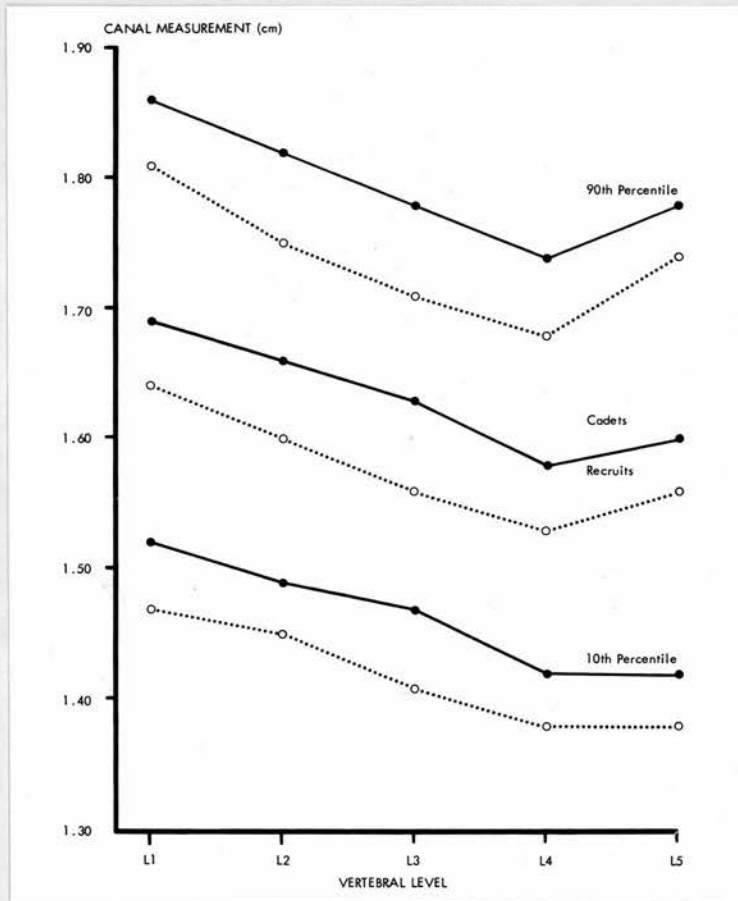
TABLE 4. MEAN AND PERCENTILE ULTRASOUND MEASUREMENTS FOR MALE AND FEMALE, 15-21 YEAR OLD SUBJECTS.

188 MALES 15-21 YEARS	Mean	S.D.	10th Percentile	90th Percentile
L.1	1.64	.14	1.47	1.81
L.2	1.60	.14	1.45	1.75
L.3	1.56	.13	1.41	1.71
L.4	1.53	.14	1.36	1.70
L.5	1.56	.15	1.38	1.74

102 FEMALES 15-21 YEARS	Mean	S.D.	10th Percentile	90th Percentile
L.1	1.69	.13	1.52	1.86
L.2	1.66	.13	1.49	1.82
L.3	1.63	.12	1.47	1.78
L.4	1.58	.13	1.42	1.74
L.5	1.60	.14	1.42	1.78

PART 2. Section 7

FIG. 18. GRAPH SHOWING MEAN AND PERCENTILE
ULTRASOUND MEASUREMENTS AT EACH LUMBAR
LEVEL, FOR 188 MALES AND 102 FEMALES,
15 - 21 YEAR OLD SUBJECTS.



The fifteen degree oblique sagittal diameter of the lumbar canal is greatest at L.1, reduces towards L.4 and tends to widen again at L.5. The canal of the nurses is slightly wider than the miners, and this is statistically significant ($p < 0.05$).

PART 2. Section 8

ULTRASOUND MEASUREMENTS OF THE LUMBAR SPINAL CANAL
IN CHILDREN (2 - 18 YEARS OF AGE).

The canal was measured in 150 children from the second to eighteenth year. These children had neither backache nor known spinal pathology. They had no lower limb deformities. Most had volunteered for ultrasound measurement whilst attending a clinic with upper limb fractures. The mean canal size at each lumbar level is compared with age in Fig. 19 and the percentiles at L.5 compared with age in Fig. 20.

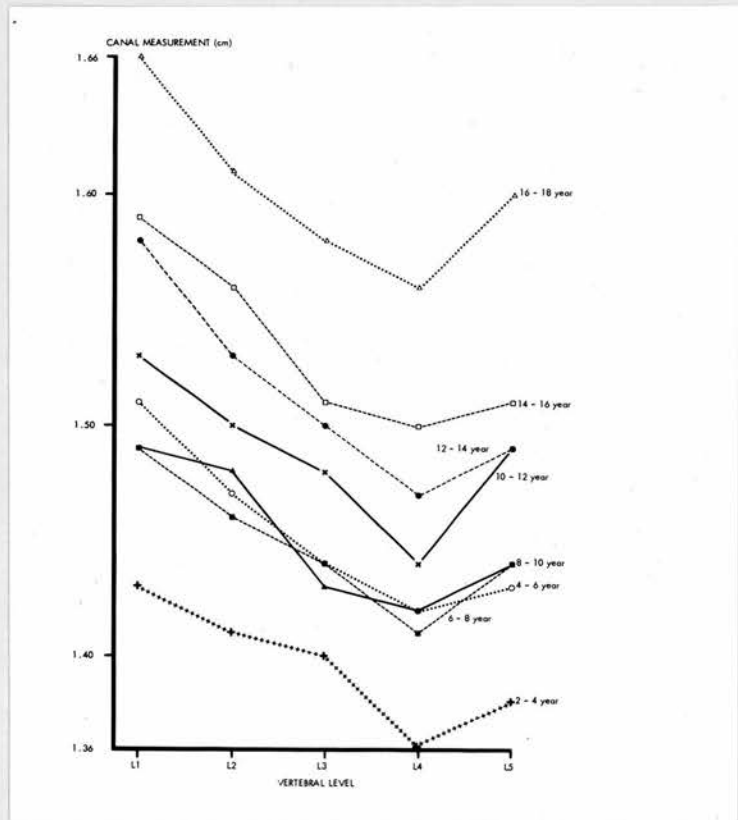


FIG.19 GRAPH TO SHOW CHILDREN'S MEAN ULTRASOUND
MEASUREMENTS AT EACH LUMBAR LEVEL RELATED TO
AGE.

PART 2. Section 8

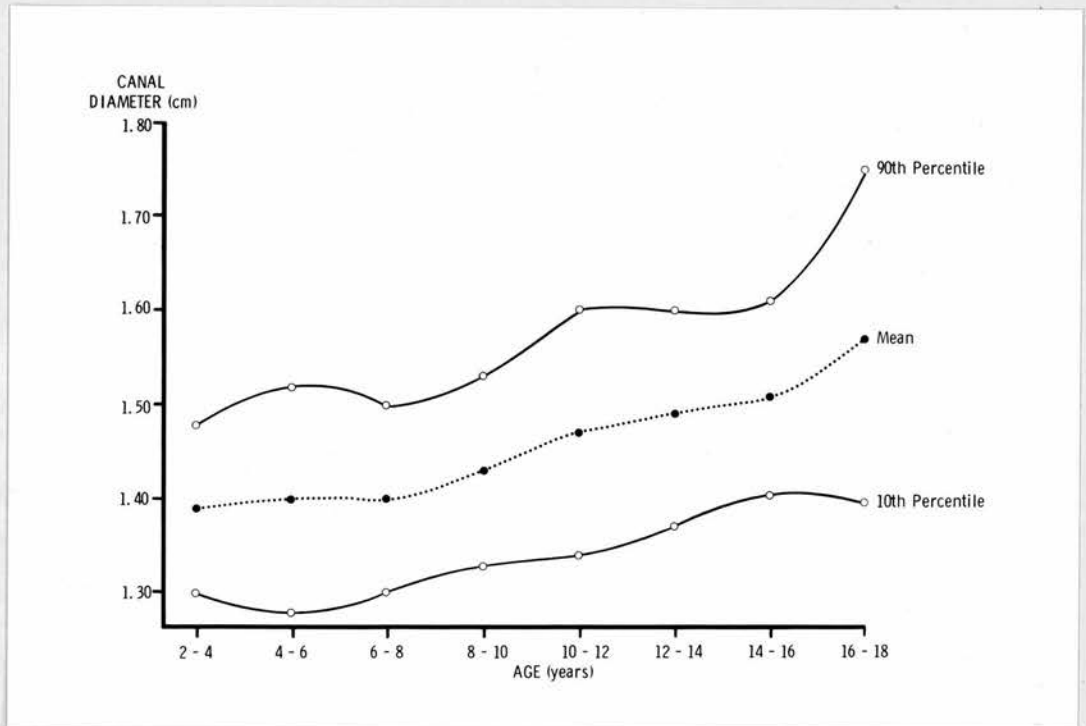


FIG. 20. GRAPH TO SHOW CHILDREN'S MEAN AND PERCENTILE ULTRASOUND MEASUREMENTS AT L.5 RELATED TO AGE.

The canal diameter is relatively wide in small children (Fig. 21). In infancy the mean oblique diameter at L.5 is already 1.36 cm., which increases to 1.58 cm. at puberty.

PART 2. Section 8

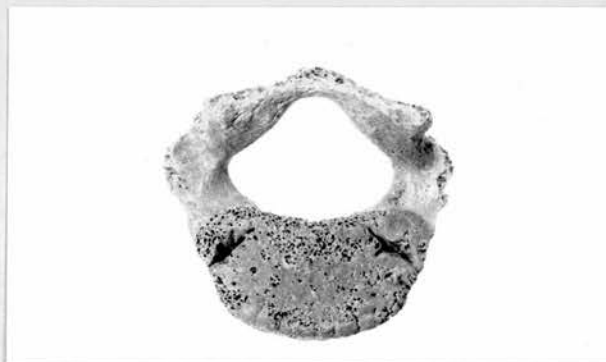


FIG. 21 PHOTOGRAPH OF FIFTH LUMBAR VERTEBRA OF AN
INFANT AND AN ADULT, DEMONSTRATING
RELATIVELY LARGE SPINAL CANAL IN INFANT.



PART 2. Section 8

The ultrasound measurements are probably artificially high in very young children, because the thin neural arch probably increases the lamina "window" through which ultrasound enters the spinal canal. It may reflect the mid sagittal rather than the fifteen degree oblique diameter, if both laminae and the apex of the neural arch are included in the "window". A mid line scan is possible in the infant, whilst the thickened spinous process absorbs the ultrasound in the older child and adult. The pattern of measurements, with the canal decreasing in size from L.1 to L.4 and increasing again at L.5, remains the same throughout growth (Fig. 19). The relative position of the cord rising within the growing spinal canal and the development of the secondary lumbar curve does not appear to affect this pattern of measurement.

PART 2. Section 9

ULTRASOUND MEASUREMENTS OF THE LUMBAR SPINAL CANAL
FROM THREE OCCUPATIONAL GROUPS BETWEEN 50 AND 65
YEARS OF AGE.

Measurements were recorded by ultrasound from three groups of subjects between fifty and sixty five years-of-age. Two hundred were underground miners who had received a financial incentive to attend for measurement. They represented fifty per cent of an underground work force in that age group at one colliery. Eighty were male sedentary workers, mostly doctors, solicitors or office staff. They were invited to attend for measurement irrespective of their experiencing any spinal symptoms, but they were not clinic patients. Fifty two were female nurses at Doncaster Royal Infirmary who volunteered for measurement.

The percentiles of canal size at each vertebral level for the three occupational groups are recorded in Table 5, and their mean values shown diagrammatically in Fig.22. Their measurements at each vertebral level are over one millimeter less than those of the young adults.

PART 2. Section 9

TABLE 5. MEAN AND PERCENTILE ULTRASOUND MEASUREMENTS FOR 50-65 YEAR OLD SUBJECTS, (MINERS, SEDENTARY WORKERS AND NURSES).

200 MINERS 50-65 YRS.	Mean	S.D.	10th Percentile	90th Percentile
L.1	1.55	.10	1.43	1.68
L.2	1.52	.10	1.39	1.64
L.3	1.48	.10	1.36	1.61
L.4	1.45	.09	1.33	1.58
L.5	1.47	.10	1.35	1.60

52 NURSES 50-65 YRS.	Mean	S.D.	10th Percentile	90th Percentile
L.1	1.55	.06	1.46	1.63
L.2	1.52	.08	1.42	1.62
L.3	1.49	.08	1.39	1.59
L.4	1.46	.09	1.35	1.57
L.5	1.48	.09	1.37	1.60

80 SEDENT- ARY WORKERS 50-65 YRS.	Mean	S.D.	10th Percentile	90th Percentile
L.1	1.55	.08	1.44	1.65
L.2	1.51	.09	1.40	1.62
L.3	1.46	.09	1.34	1.58
L.4	1.43	.07	1.34	1.53
L.5	1.45	.07	1.36	1.55

PART 2. Section 9

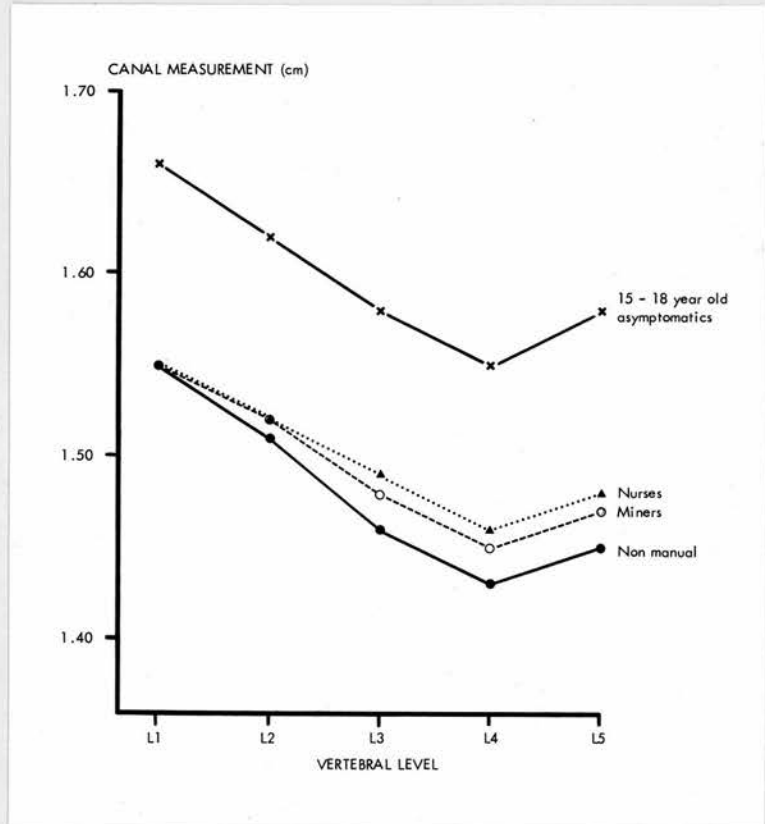


FIG. 22. GRAPH OF MEAN ULTRASOUND MEASUREMENTS AT EACH LUMBAR LEVEL FOR 50-65 YEAR OLD SUBJECTS, (200 MINERS, 80 MALE SEDENTARY WORKERS AND 52 NURSES), COMPARED WITH MEAN MEASUREMENTS OF THE 15-21 YEAR OLD SUBJECTS.

There is an age-related narrowing of the canal when measured by ultrasound. It is not clear, however, whether this is apparent or real.

It could be argued that if the "window" becomes reduced in size with age, this will produce an apparent narrowing of the canal.

PART 2. Section 9

Section 3 described how the point of measurement from the posterior surface of the vertebral body is probably closer to the medial side of the beam than to the lateral side, (Fig. 23), and concentric narrowing of the "window" would shift the point of measurement laterally. However, bone generally becomes less dense with age which would widen the window and increase the measurement.

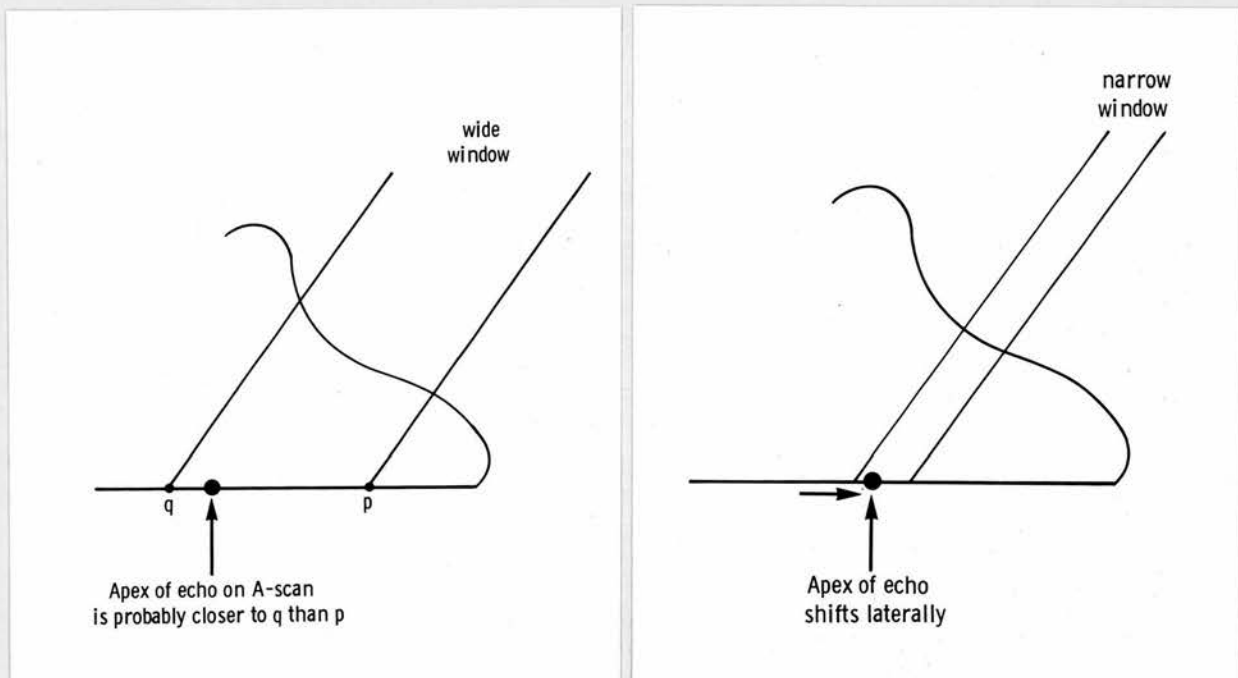


FIG. 23. DIAGRAM TO SHOW HOW THE POINT OF MEASUREMENT ON THE POSTERIOR SURFACE OF THE VERTEBRAL BODY PROBABLY SHIFTS Laterally WITH A REDUCTION IN THE SIZE OF THE "WINDOW".

If the lamina was thickened with bony hypertrophy and degenerative change, the "window" would probably reduce in size concentrically, with a reduction in the canal measurement.

PART 2. Section 9

One would expect this to be most apparent in the miners who had worked for three or four decades underground, some of them being involved in heavy work in confined spaces in early adult life prior to mechanisation of the coal-industry. Their measurements, however, are slightly wider than the men employed in sedentary occupations. It is possible that the miners with narrow canals have selected themselves out of underground work, and that those with troublesome narrow spines have taken other employment. If, however, demanding physical work significantly affects the diameter of the spinal canal, it should have been demonstrated in this study.

It is difficult, therefore, to explain the cause of the age-related narrowing of ultrasound measurements of the spinal canal. It is important that it is recognised however, when matching pathological groups with the general population.

The failure of occupation to affect the size of the canal suggests that the narrow canal should be considered to be developmental rather than degenerative. Degenerative change may produce localised encroachment, (Postacchini et al 1980), but not affect the general size of the canal.

The older nurses' canal is slightly wider than that of the sedentary men, but this is not statistically significant ($p > 0.05$).



PART 2. Section 10 COMPARISON BETWEEN RIGHT AND LEFT SIDE OF THE CANAL.

Measurements were obtained bilaterally from 430 of the subjects examined. The mean difference between the two sides and the standard deviation for each vertebral level is shown in Table 3. Although the difference between the two sides is not usually great, it is necessary to measure both sides of the canal if it is suspected that small differences in size can have clinical significance.

CONCLUSIONS

The oblique sagittal diameter of the lumbar canal measured by ultrasound is related to age. The mean values are relatively large in children, gradually increase towards puberty, and reduce again in later adult life. This reduction is not related to occupation. The young female canal is slightly wider than the male.

PART 3

ANTHROPOMETRIC MEASUREMENTS

PART 3. Section II ANTHROPOMETRIC MEASUREMENT

Anthropometric measurements were taken from one hundred male mining recruits between sixteen and eighteen years of age, to correlate with the lumbar canal diameters measured by ultrasound on the left side of the canal.

The following measurements were taken by one examiner and recorded by a scribe.

<u>Thigh Circumference</u>	measured with a steel tape, just below the gluteal skin fold on the right and left sides.
<u>Calf Circumference</u>	measured with a steel tape, at the level of maximum diameter, on the right and left sides.
<u>Bicondylar femur diameter</u>	measured on the left leg with vernier calipers.
<u>Tibial length</u>	measured with the Harpenden Anthropometer and straight arm pieces as the subject sat with leg crossed over the other knee, from the upper border of the tibia medially to the tip of the medial malleolus, on right and left sides.
<u>Foot length</u>	measured with Harpenden arm pieces from the posterior heel bony prominence to the tip of the big toe, on right and left sides, with the subject cross legged.
<u>Lower Limb length</u>	measuring with a steel tape from the anterior superior iliac spine to the tip of the medial malleolus on right and left sides.
<u>Pubis to Heel</u>	measuring with a steel tape from the superior border of the pubis to the medial malleolus on the right and left sides.
<u>Head circumference</u>	measuring the maximum circumference with a steel tape.
<u>Upper arm circumference</u>	measuring with a steel tape. The subject stood with the arm hanging loosely by the side, and pen markers were placed on the skin over the tip of the acromion, the articular surface of the head of the radius, and the mid point between these two. The circumference was recorded on the left side.

PART 3. Section II

<u>Triceps skin fold</u>	measured with skinfold calipers, at the mid point of the upper arm on the left.
<u>Subscapular skin fold</u>	measured with skin fold calipers at the lower angle of the scapula on the left.
<u>Calf skin fold</u>	measured with skin fold calipers on the posterior calf on the left.
<u>Skull antero-posterior</u>	measuring with the Harpenden Anthropometer and straight arm pieces, at the maximum antero-posterior diameter.
<u>Skull lateral</u>	measuring with the Harpenden Anthropometer and straight arm pieces at the maximum diameter above the ears.
<u>Chest antero-posterior</u>	measuring with the Harpenden Anthropometer and curved arm pieces at the point of maximum diameter from the sternum to the spinous processes posteriorly in the same horizontal plane.
<u>Chest lateral</u>	measured with the Harpenden Anthropometer and curved arm pieces at the level of maximum diameter.
<u>Biacromial diameter</u>	measuring with the Harpenden Anthropometer and straight arm pieces between the outer margins of the acromion.
<u>Iliio-cristal diameter</u>	measuring with the Harpenden Anthropometer and straight arm pieces between the outer margin of the iliac crests.
<u>Total arm length</u>	measuring with a steel tape with the subject standing and the arm hanging loosely with the palm facing backwards and the fingers extended, from the lateral border of the acromion to the tip of the middle finger on the left.
<u>Upper arm length</u>	measured with a steel tape with the arm in the same position as for total arm length measurement, from the acromion to the articular surface of the head of radius on the left.
<u>Forearm and hand length</u>	measured with a steel tape with the hand prone on a table, and the elbow flexed, from the articular surface of the head of radius to the tip of the middle finger on the left.
<u>Forearm length</u>	measured with a steel tape with the arm positioned as for measuring the forearm and hand, from the articular surface of the head of radius to the tip of the ulna styloid on the left.
<u>Hand length</u>	measured with a steel tape with the hand prone on a table, from the tip of the ulna styloid to the tip of the middle finger on the left.
<u>Bicondylar diameter of the humerus</u>	measured with vernier calipers on the left.

PART 3. Section II

Span

measured with the Harpenden measuring table, between the middle finger tips, with the subject seated at the table and leaning forwards to stretch the arms laterally, with the chin on the table as far as possible.

Supine length

measured with the Harpenden measuring table, the subject supine, the chin 'well up', and the feet flat with the end plate.

Crown to rump

measured with the Harpenden measuring table, as for supine length, with the hips flexed to ninety degrees.

The pelvis obliquity

was recorded if present, by noting the position of the anterior superior iliac spines.

PART 3.

REPEATABILITY OF ANTHROPOMETRIC DATA

Anthropometric measurements were recorded from two of the mining recruits on two separate occasions, and the difference between measurements shown in Table 6.

TABLE 6. REPEATABILITY OF ANTHROPOMETRIC MEASUREMENTS ON TWO SUBJECTS

Two subjects were measured twice and the differences recorded in cms.

Measurement	Subject 1	Subject 2	Mean Difference
Head circumference	.3	.5	.4
Upper arm circumference (L)	1.0	0	.5
Thigh circumference (L)	.5	.5	.5
(R)	0	2.0	1.0
Calf circumference (L)	.1	.5	.3
(R)	.7	1.0	.85
Triceps skin fold (L)	.04	.02	.03
Subscapular skin fold (L)	.02	.10	.06
Medial calf skin fold (L)	.02	.02	.02
Skull AP	.5	.1	.3
Lateral	0	0	0
Chest AP	.5	.3	.4
Lateral	0	.9	.45
Biacromial width	.6	1.1	.85
Bi-iliocrystal width	0	.2	.1
Total arm length (L)	.5	1.2	.85
Upper arm length	0	.5	.25
Forearm and hand length (L)	.4	1.0	.7
Forearm length (L)	.5	2.0	1.25
Hand length (L)	0	.2	.1

PART 3

Measurement	Subject 1	Subject 2	Mean Difference
Bicondylar humerus (L)	.3	.1	.2
Bicondylar femur (L)	.2	0	.1
(R)	.6	.2	.4
Tibia (L)	.5	1.0	.75
(R)	.3	1.0	.65
Foot (L)	0	.3	.15
(R)	0	.5	.25
Span	.4	-	.2
Total lower limb length (L)	.5	1.0	.75
(R)	.5	0	.25
Pubis to heel (L)	2.4	1.0	1.7
(R)	2.7	1.0	1.85
Supine length	.8	2.0	1.4
Supine length (CR)	1.5	2.0	1.75
Pelvis (level or not)	Yes	Yes	

The pubis to heel measurement was repeated in twenty subjects with a mean difference of $1.4 \text{ cm} \pm 1.3 \text{ cm}$.

PART 3.

RESULTS (100 subjects)

The mean and standard deviation for each measurement is shown in Table 7, and in addition, the difference between the right and left sides of the lower limb measurements. The correlation coefficient with the ultrasound measurement of the spinal canal was calculated for each anthropometric measurement, and correlations also made with the difference in measurement at L.4 and L.5

TABLE 7. MEAN AND STANDARD DEVIATION FOR ANTHROPOMETRIC MEASUREMENTS AND CORRELATION WITH ULTRASOUND MEASUREMENTS

Anthropometric Measurement	Mean (cms)	SD	Correlation coefficient for					L.5<L.4	L.5>L.4
			L.1	L.2	L.3	L.4	L.5		
Thigh circumf. L-R	0.07	0.74	-.007	-.001	-.001	.02	-.05	-.14	-.04
Calf circumf. L-R	0.10	0.51	.03	.05	.03	.06	.09	-.14	.16
Bicond. Femur L	0.02	0.17	-.02	.009	-.008	-.009	.02	.15	.21
Tibia L-R	0.13	0.78	-.03	-.06	-.08	-.02	.007	-.04	.09
Foot L-R	0.17	0.58	-.05	-.02	.02	.07	.02	.07	-.20
Lower Limb L-R	0.18	0.57	.01	-.07	-.03	-.01	.03	.45*	.0006
Pubis/Heel L-R	0.06	0.40	.17	.21	.27**	.23*	.19	-.48*	.11
Weight (Kgs)	61.6	9.91	-	-	-	-	-	-	-
Head Circumf.	55.98	1.85	.10	.09	.06	.08	.20*	.16	.12
Arm Circumf.	26.10	2.99	.04	-.02	-.06	-.04	.04	.04	.21
Thigh Circumf. L	52.69	5.56	.20*	.14	.10	.13	.22*	-.05	.11
Thigh Circumf. R	52.62	5.58	.20*	.14	.10	.13	.23*	-.02	.11
Calf Circumf. L	34.16	2.88	.11	.07	.05	.09	.17	-.16	.18
Calf Circumf. R	34.06	2.86	.10	.06	.04	.08	.16	-.13	.16
Triceps SF	0.83	0.34	.06	-.006	.02	.03	.13	-.07	.10
Subscap SF	0.80	0.30	.008	.003	-.03	-.008	.06	-.22	.10
Calf SF	0.83	0.34	-.05	-.10	-.09	-.02	.04	-.17	.08

PART 3.

Anthropometric Measurement	Mean (cms)	SD	Correlation coefficient for						
			L.1	L.2	L.3	L.4	L.5	L.5<L.4	L.5>L.4
Skull AP	19.05	0.70	.11	.12	.09	.11	.13	-.11	-.07
Skull Lat	15.06	0.56	.23*	.23*	.20*	.22*	.25**	-.03	.03
Chest AP	18.58	2.08	.04	.02	-.002	.02	.03	-.03	-.03
Chest Lat	27.09	2.07	.10	.08	.04	.05	.09	-.003	-.03
Biacromial	38.35	2.18	.23*	.22*	.15	.13	.18	.25	.03
Bi-ilocrystal	25.65	2.07	.13	.12	.05	.05	.10	.005	.08
Total Arm	74.45	3.28	.24**	.21*	.20*	.14	.13	.05	.02
Upper Arm	32.36	2.69	.007	.02	-.001	-.03	-.04	-.06	.03
Fore & Hand	46.04	2.16	.11	.08	.04	-.009	-.006	-.10	.05
Forearm	25.99	1.69	.04	-.02	-.01	-.03	-.05	-.17	.06
Hand	20.71	0.98	.13	.11	.09	.02	.10	.13	.07
Bicond Humerus	7.06	0.51	.04	.04	.04	-.07	-.009	-.02	.19
Bicond Femur L	9.88	0.60	.06	.06	.01	.03	.13	-.13	.17
Bicond Femur R	9.87	0.60	.06	.06	.02	.04	.12	-.17	.11
Tibia L	38.30	1.96	.14	.06	.07	-.10	.15	-.01	.08
Tibia R	38.17	2.01	.15	.08	.10	.11	.14	.005	.04
Foot L	25.45	1.29	.15	.16	.14	.15	.22*	.14	-.007
Foot R	25.27	1.36	.16	.16	.13	.11	.20*	.09	.08
Span	174.78	6.78	.24*	.23*	.18	.17	.17	.004	.004
Lower Limb L	91.76	3.92	.16	.11	.12	.11	.16	.02	.05
Lower Limb R	91.95	3.96	.16	.11	.12	.11	.15	-.07	.05
Pubis/Heel L	80.93	3.63	.21*	.13	.16	.14	.18	-.10	.02
Pubis/Heel R	80.99	3.58	.19	.11	.13	.12	.16	-.06	.04
Supine	175.29	5.64	.19	.17	.13	.15	.12	-.11	-.004
CR	93.08	3.58	.13	.14	.09	.11	.003	-.13	-.12
Pelvis	0.69	0.46							

level or not
ie. 0 or 1

Levels of Significance - * p < .05

** p < .01

PART 3.

The canal size showed a correlation of .2 or more with the following anthropometric measurements.

Thigh circumference right and left	.23 and .22 at L.5
Biacromial diameter	.23 at L.1
Total arm length	.24 at L.1
Foot length right and left	.20 and .22 at L.5
Span	.24 at L.1
Pubis to heel on the left	.21 at L.1
Pubis to heel inequality	.27 at L.3

The degree in which L.5 was less than L.4 showed a correlation of .48 with pubis to heel inequality and .45 with lower limb inequality.

A multiple regression analysis was applied to express the size of the spinal canal in terms of combinations of the anthropometric measurements. From 'n' observations (n - one hundred mining recruits) it was necessary to obtain estimates of the partial regression coefficients, ($b_1, b_2 \dots b_p$), and hence obtain an estimated regression equation,

$$y = a + b_1 x_1 + b_2 x_2 + \dots b_p x_p$$

where y is the predicted value of the spinal canal measurement, a is the intercept, and

$x_1 x_2 \dots x_p$ the different anthropometric measurements.

PART 3.

Three anthropometric measurements (x_1 x_2 x_3) in the equation give over seven thousand possible combinations, and therefore for practical purposes p is restricted to three of the measurements.

For each combination, the multiple correlation coefficient R was calculated, and its significance estimated using the F distribution.

The significance of each b_j was also tested with the t distribution on $n-p-1$ degrees of freedom.

The highest multiple correlation coefficients at each vertebral level are shown in Table 8.

PART 3.

The highest multiple correlation coefficients at each vertebral level are shown in Table 8.

TABLE 8. HIGHEST MULTIPLE CORRELATION COEFFICIENTS WITH ULTRASOUND MEASUREMENTS AT EACH VERTEBRAL LEVEL.

<u>L.1</u>	Skull lateral (+)	Total arm length (+)	Tibia inequality (-)	R = .33 ($p < .01$)
<u>L.2</u>	Skull lateral (+)	Total arm length (+)	Forearm length (-)	R = .36 ($p < .01$)
<u>L.3</u>	Skull lateral (+)	Pubis to Heel, L. (+)	Pubis to Heel, R. (-)	R = .35 ($p < .01$)
	Pubis to heel inequality (-)	Total arm length (+)	Forearm length (-)	R = .36 ($p < .01$)
<u>L.4</u>	Skull lateral (+)	Total arm length (+)	Forearm and hand (-)	R = .32 ($p < .05$)
	Pubis to heel (+)	Forearm (-)	Span (+)	R = .32 ($p < .05$)
<u>L.5</u>	Skull lateral (+)	Tibia inequality (-)	Foot length right or left (+)	R = .39 ($p < .01$)
	Skull lateral (+)	Forearm length (-)	Pubis to heel right or left. (+)	R = .40 ($p < .01$)

PART 3

The highest correlation with the difference between L.5 and L.4 is shown in Table 9.

TABLE 9. HIGHEST CORRELATION COEFFICIENTS WITH ULTRASOUND WHEN L.5 WAS LESS THAN L.4.

When L.5 was less than L.4 was..... (n = 24)	Calf circumference inequality (-)	Pubis to heel inequality (-)	Biacromial diameter (+)	R = .67 ($p < .01$)
	Thigh circumf. inequality (-)	Pubis to heel inequality (-)	Biacromial diameter (+)	R = .65 ($p < .01$)

A positive sign (+), indicates that that anthropometric measurement gives a positive contribution to the canal size.

A negative sign (-), indicates a negative contribution to canal size.

PART 3.

This can be alternatively expressed:

<u>At L.1</u>	a <u>small canal</u> is associated with (R = .33)	a small <u>skull lateral</u> a small <u>total arm length</u> and a large degree of <u>tibial inequality</u>
<u>At L.2</u>	a <u>small canal</u> is associated with (R = .36)	a small <u>skull lateral</u> a small <u>total arm length</u> and a long <u>forearm</u>
<u>At L.3</u>	a <u>small canal</u> is associated with (R = .35)	a small <u>skull lateral</u> a small <u>pubis-to-heel left</u> a large <u>pubis-to-heel right</u>
	a <u>small canal</u> is associated with (R = .36)	a large inequality of <u>pubis-to-heel</u> measurement. a small <u>total arm length</u> and a long <u>forearm</u> .
<u>At L.4</u>	a <u>small canal</u> is associated with (R = .32)	a large <u>inequality of pubis to heel</u> measurement. a small <u>span</u> and a long <u>forearm</u>
	a <u>small canal</u> is associated with (R = .32)	a small <u>skull lateral</u> a small <u>total arm length</u> and a long <u>forearm and hand</u> .
<u>At L.5</u>	a <u>small canal</u> is associated with (R = .39)	a small <u>skull lateral</u> a large degree of <u>tibial inequality</u> and a short <u>foot</u> (right or left)
	a <u>small canal</u> is associated with (R = .40)	a small <u>skull lateral</u> a small <u>pubis to heel</u> (right or left) and a long <u>forearm</u> .

The difference when L.5 is less than L.4
is greatest when associated with
(R = .67)

and when associated with
(R = .65)

a large inequality of calf
circumference.
a large inequality of pubis-to-heel
measurement and a small biacromial
diameter.

a large inequality of thigh circumference
a large inequality of pubis-to-heel
measurement and a small biacromial
diameter.

PART 3.

DISCUSSION

If it is accepted that back pain is more common in the subject with a narrow spinal canal, it would be helpful to find a body measurement with a high correlation to canal size. However, no single anthropometric measurement has a sufficiently high correlation with canal size to suggest that a particular body build is associated with a wide or narrow canal.

The anthropometric data does, however, provide some information about factors involved in the growth and development of the spinal canal.

I) CANAL SIZE CORRELATED WITH LOWER LIMB MEASUREMENTS

A correlation of .2 or more for thigh circumference, foot length, pubis to heel, and for total arm length, span and biacromial diameter, suggests that factors that are responsible for limb development are also related to development of the canal.

The multiple regression analysis confirms the correlation between canal size and both pubis-to-heel and foot length. When either of these are combined with two other particular measurements, a correlation of .40 and .39 are obtained with canal size at L.5. It is reasonable to believe that large lower limbs are accompanied by an increase in nervous tissue, and that this would be accommodated in a larger

PART 3.

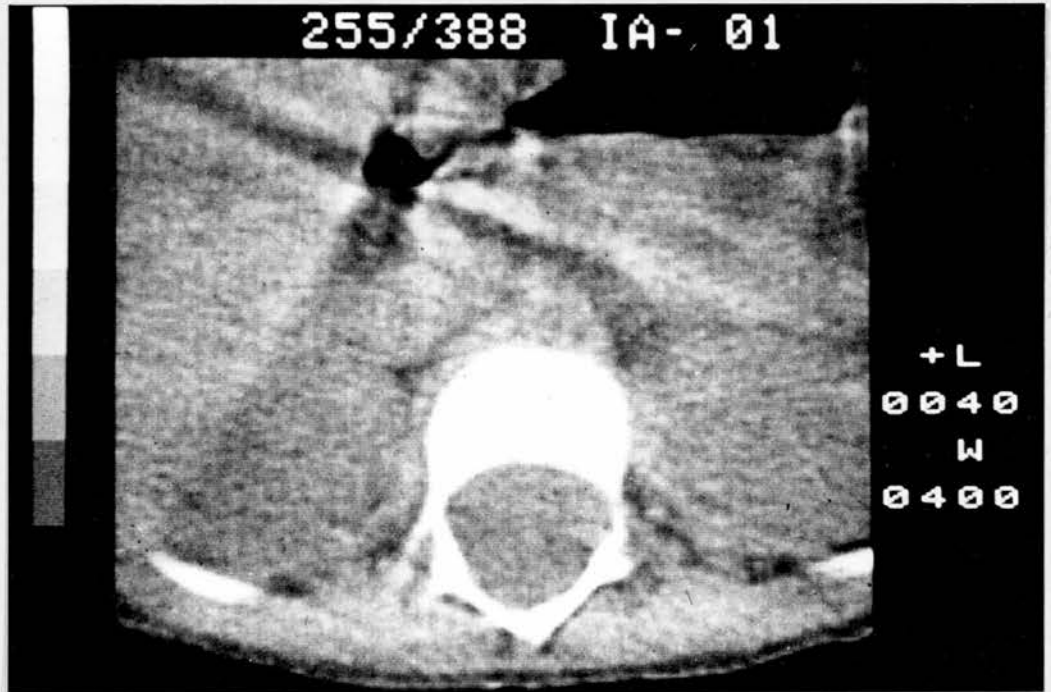
canal. The best correlations however are at L.5 in the multiple regression equations and not at other lumbar levels, except when pubis-to-heel gives an isolated correlation with canal size .21 at L.1.

2) CANAL SIZE CORRELATED WITH SKULL LATERAL MEASUREMENT

The skull lateral diameter repeatedly recurs with the best correlations at each lumbar level when combined with other anthropometric measurements in the multiple regression equations. Skull growth depends largely upon the epigenetic factors of its contents (Limburgh 1972, Roth 1973), being related to the growth of the brain, as in hydrocephalus or microcephally. The growth of the spinal canal is probably a response to some degree to the epigenetic factors of its contents. It is difficult to accept an explanation for the correlation with skull lateral diameter, other than that a subject with a large skull and large brain also has a large cord and nerve roots, and that these exert an influence on the surrounding bony structures. There is pathological evidence that the growth of the spinal canal is affected by its contents, when an intra or extradural tumour causes the growing canal to expand (Fig. 24).

PART 3.

FIG. 24. C.A.T. SCAN OF EXPANDED THORACIC SPINAL CANAL IN A CHILD, CAUSED BY TUMOUR.



The fact that only the skull lateral diameter and not the antero-posterior diameter or circumference shows a correlation with canal size, suggests that this part of the brain may be more significantly related to the size of the spinal cord, being the site of the motor and sensory cortex.

3) CANAL SIZE CORRELATED WITH LOWER LIMB INEQUALITY

Inequality of lower limb measurements show a surprising correlation with canal measurement. Pubis-to-heel inequality has a correlation of .27 with canal size at L.3. When including two other anthropometric measurements with pubis-to-heel inequality in the multiple regression equation,

PART 3.

$R = .36$ at L.3 and $R = .32$ at L.4. Tibial inequality appears in the multiple regression equation as a high correlation at L.1; $R = .33$ and at L.5 $R = .39$. It suggests that factors that are responsible for unequal growth of the lower limbs also affect canal development.

4) CANAL SIZE CORRELATED WITH UPPER LIMB DISPROPORTION OF FOREARM AND UPPER ARM

Relatively high correlations are recorded at L.2, L.3 and L.4 when disproportionate upper limb measurements are included in the equations. A small total arm length, with a long forearm (or forearm and hand at L.4) is related to a small canal. It is an interesting observation, and difficult to explain.

5) CORRELATIONS WHEN L.5 IS LESS THAN L.4

In the majority of subjects, the ultrasound measurements are equal or greater at L.5 than L.4. Photographic measurements from skeletons in Section 12, suggest that in the few subjects where L.5 is less than L.4, there is a probability of the canal being trefoil in shape. It was therefore considered to be a useful exercise to apply multiple regression analysis to those 24 subjects whose canal measurements at L.5 were less than L.4.

PART 3.

The best correlations are found when inequality of lower limb measurements are included in the equation. Inequality of calf circumference, thigh circumference and pubis-to-heel are included in the equations, giving the best correlations. If a canal with L.5 measurements less than L.4 does reflect the shape of the canal, then the anthropometric data suggests that factors affecting the unequal growth of the lower limbs also affect the development of the canal's trefoil shape.

It is interesting that the biacromial diameter is included in the two best equations, a small biacromial diameter being related to a large drop in measurements from L.4 to L.5. As there was a correlation between canal size and upper limb measurements, so there appears to be a correlation between canal shape and upper limb development. It suggests that the shape and size of the lumbar canal is not dependent upon the anatomy of the lower limbs alone.

The high correlation coefficients of .65 - .67 are surprising and add weight to the above observations. Although the numbers are relatively small (n=24) the levels of significance are $p < .01$.

The skull lateral measurement does not appear in any of the best multiple regression equations when comparing the degree of difference of measurement when L.5 is less than L.4, yet it appears in all the equations for canal size from L.1 to L.5. This does lend support to the

PART 3.

conclusion that a difference in measurement between L.4 and L.5 reflects the shape of the canal and is not just recording a canal that is disproportionately small in size at L.5.

CONCLUSIONS

Correlations between ultrasound canal measurements and anthropometric data suggests that the canal's growth is related to its neural contents, (there being correlations between canal size and skull lateral, and canal size and lower limb measurements). Other factors appear to affect the canal independently, factors which influence lower limb inequality, and clavicular development.

PART 4

DIRECT MEASUREMENTS OF THE LUMBAR SPINAL CANAL
FROM SKELETONS

PART 4. Section 12

MEASUREMENT OF THE LUMBAR SPINAL CANAL FROM THE
DIRECT MEASUREMENT OF SKELETONS

The best documented palaeo-pathology of the spine is degenerative change, (Ingelmark 1956). It is only in recent years that the normal variations in the size and shape of the spinal canal has been recorded by Domminisse (1975), Baddeley (1976) and Eisenstein (1977 and 1980). They have measured the mid-sagittal and the interpedicular diameters of the lumbar spine and have recorded the number of canals with the trefoil configuration.

The ultrasound measurement of the spinal canal is in the fifteen degree oblique sagittal plane, and therefore the normal range of this measurement was sought from a skeletal population. It also provided an opportunity to determine more of the normal anatomy of the lumbar spinal canal than was available from the literature. It was apparent that to state that the trefoil shape was either present or absent was misleading, and that the trefoil configuration at the lower lumbar levels was a matter of degree. A photographic method was devised to measure this quantitatively, and relate this to the cross sectional area, and other canal and vertebral measurements.

PART 4. Section 12

FIG. 25. FIVE LUMBAR VERTEBRAE FROM THE POUNDBURY COLLECTION



The lumbar vertebrae were examined from three populations.

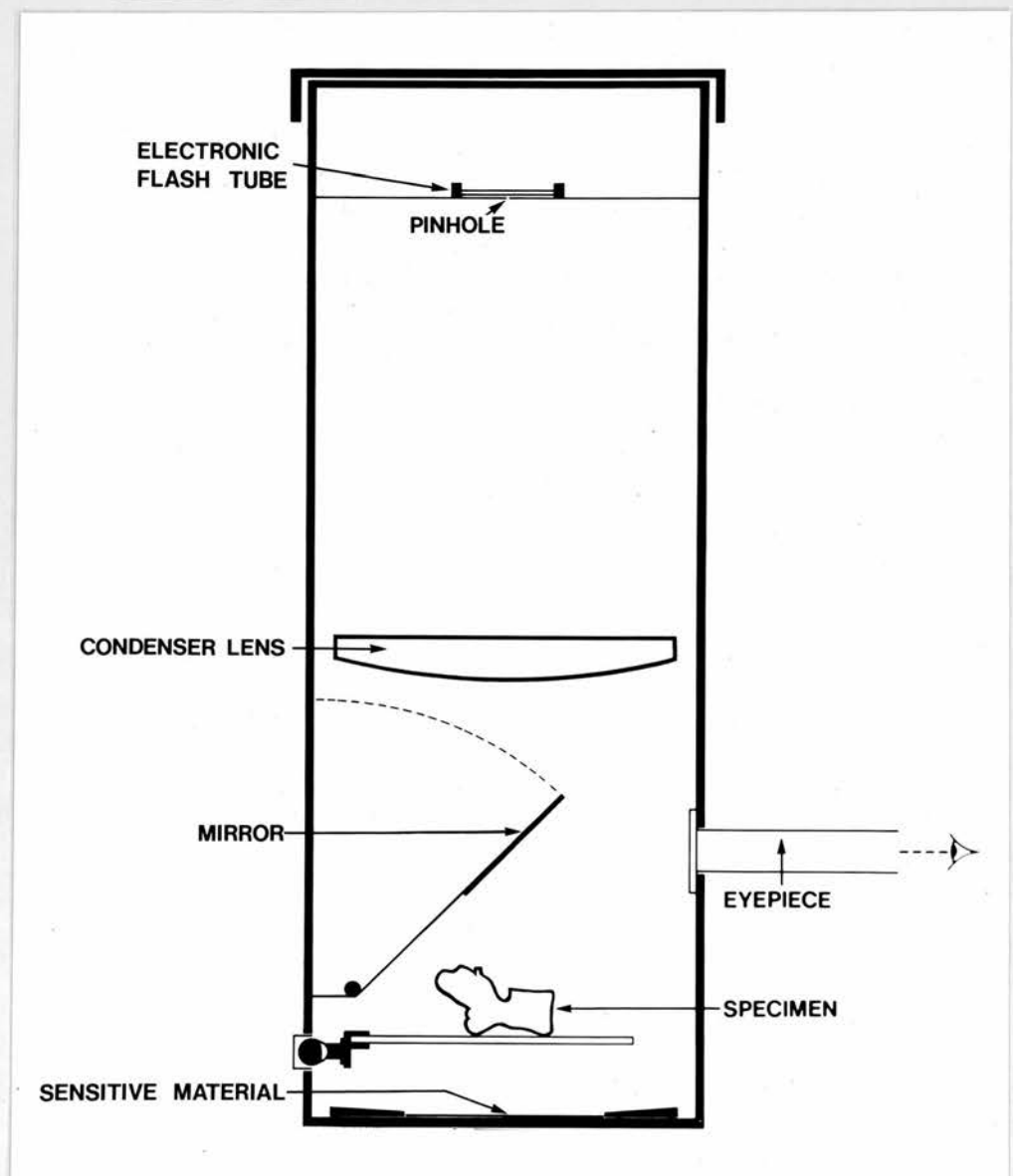
- a) A Romano-British population, fourth century A.D. from Poundbury, Dorset, loaned by the British Museum, (Green 1974). It included vertebrae from 119 adult spines, 77 being complete, and also 22 children's spines.
- b) A collection of spines from Eccles, belonging to the sub-Roman and Anglo-Saxon peoples of Kent, dating from the mid centuries of the first millenium A.D., loaned by Bradford University. There were vertebrae from 61 adult spines, 31 being complete, and in addition, 5 children's spines.

PART 4. Section 12

- c) A twentieth century collection loaned from Edinburgh University, mainly of Indian origin, including 60 adult spines, 57 being complete.

A photographic box was designed (Fig.26) to produce a silhouette photograph of the spinal canal with an unmagnified image. The light source was a photographic flash gun. A pin-hole was necessary for a sharp light source, and this was carefully constructed by grinding a spherical depression in a metal plate until the plate was just penetrated (Cloud 1977).

FIG. 26. DIAGRAM OF THE PHOTOGRAPHIC BOX

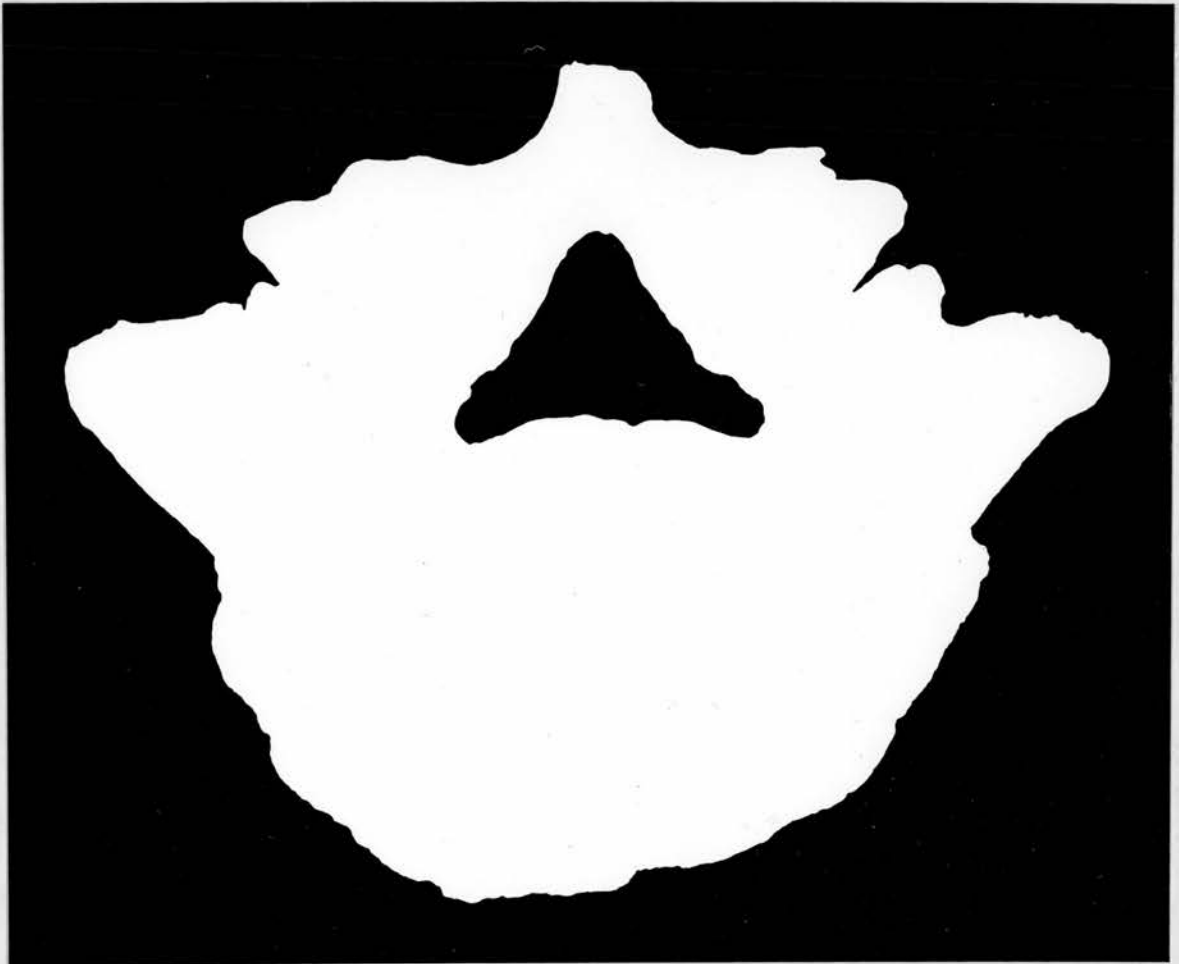


PART 4. Section 12

The light was passed through a condensor to obtain parallel light. The vertebra being examined was positioned on a glass plate, the angle of which could be manually tilted through the plate's mounting on a universal joint. The construction of the box permitted the examiner to observe the position of the vertebra through an eye-piece and a mirror. The vertebra was moved on the glass plate until the centre of the canal was superimposed on a point reflected from the base-plate, through the canal and mirror. When the vertebra was correctly positioned on the glass plate, the plate was tilted until the cranial and caudal edge of the posterior surface of the vertebral body were superimposed. It was considered that the maximum amount of light would then pass through the spinal canal. The hinged mirror was then lifted to the back of the box, a film placed on the base-plate, and the flash gun operated by a foot switch. A silhouette photograph was obtained, (Fig. 27).

PART 4. Section 12

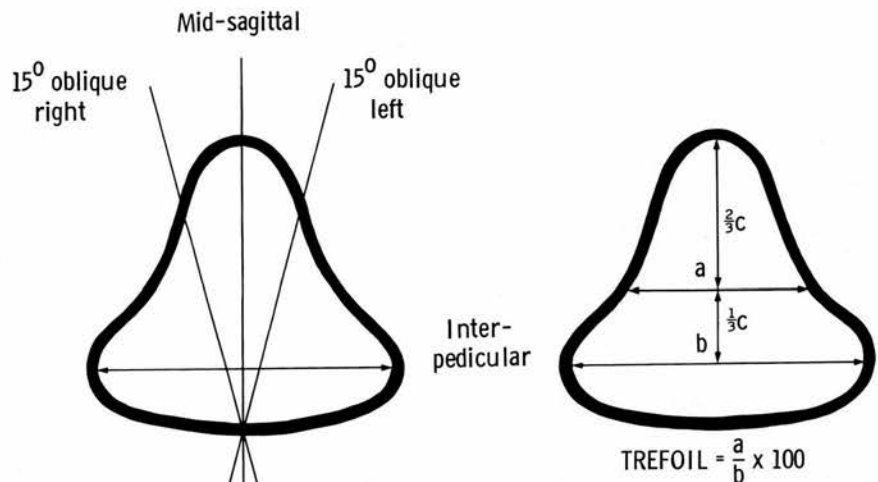
FIG. 27 SILHOUETTE PHOTOGRAPH OF L.5 VERTEBRA



PART 4. Section 12

The parameters measured, and shown in Fig. 28, were interpedicular diameter, mid-sagittal diameter, fifteen degree oblique diameters, the canal area measured with a planimeter, and an estimate of the degree of 'trefoilness' from the ratio of two transverse diameters.

FIG.28. DIAGRAM OF THE PARAMETERS OF THE SPINAL CANAL MEASURED.



MEASUREMENTS TAKEN FROM SILHOUETTE PHOTOGRAPHS

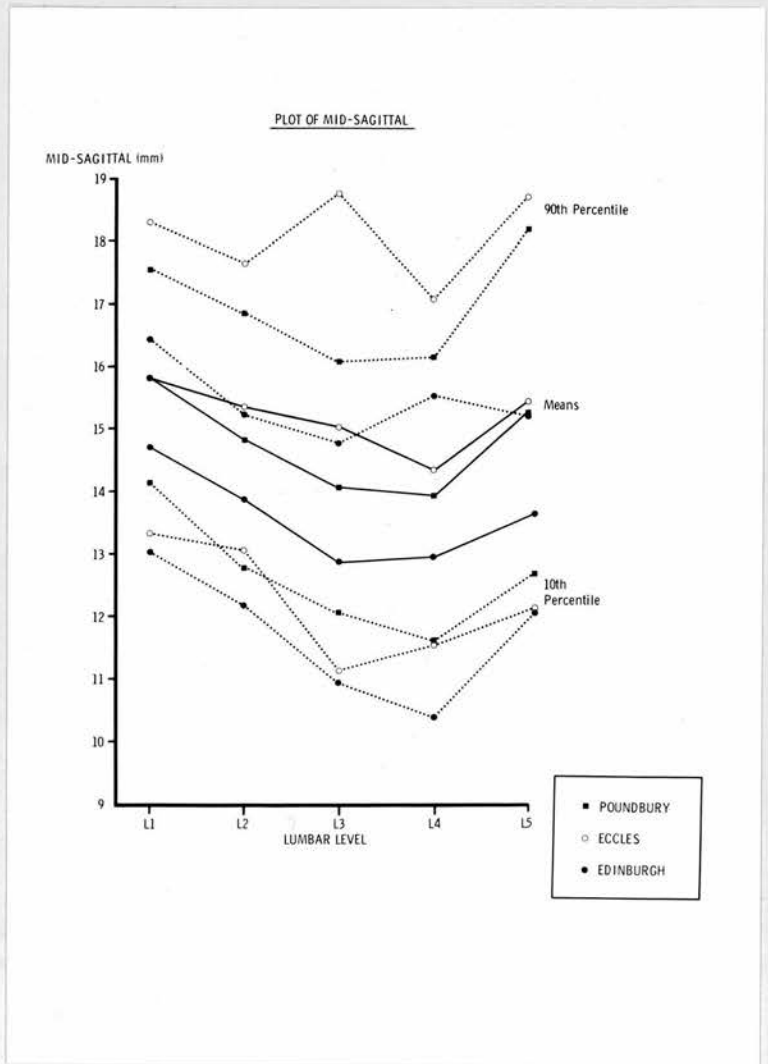
PART 4. Section 12

RESULTS

The measurements of these parameters from the three populations are shown in Figs. 29, 30, 31, 32 and 33.

The mean mid-sagittal diameter, the fifteen degree oblique diameter, and the area decreased from L.1 to L.4, increasing again at L.5. The interpedicular diameter and the degree of 'trefoilness' increased from L.1 to L.5.

FIG. 29 GRAPH OF MEAN AND PERCENTILE MID-SAGITTAL
DIAMETER OF THREE SKELETAL POPULATIONS.



PART 4. Section 12

FIG. 30 GRAPH OF MEAN AND PERCENTILE FIFTEEN DEGREE OBLIQUE SAGITTAL DIAMETER OF THREE SKELETAL POPULATIONS

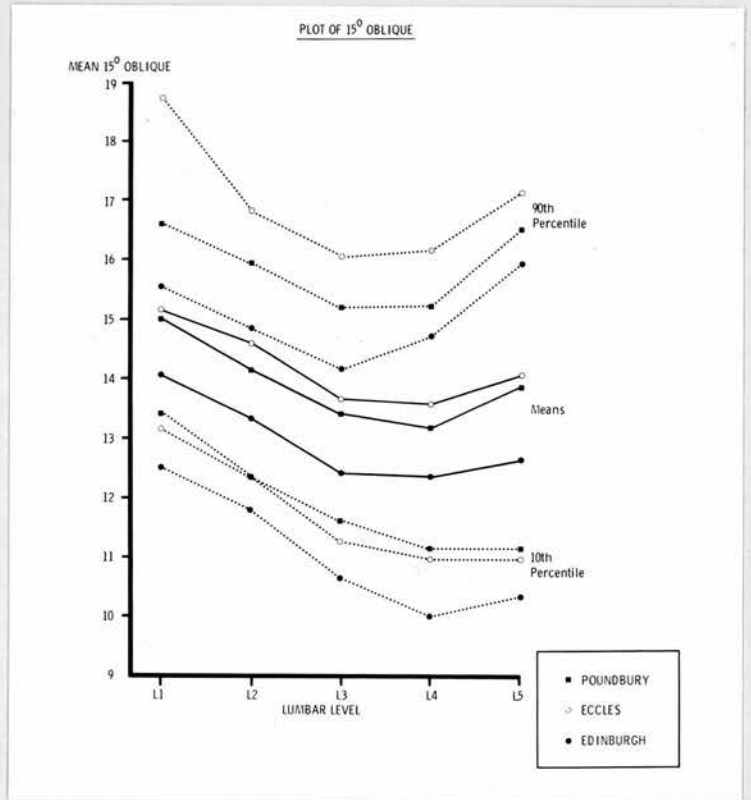
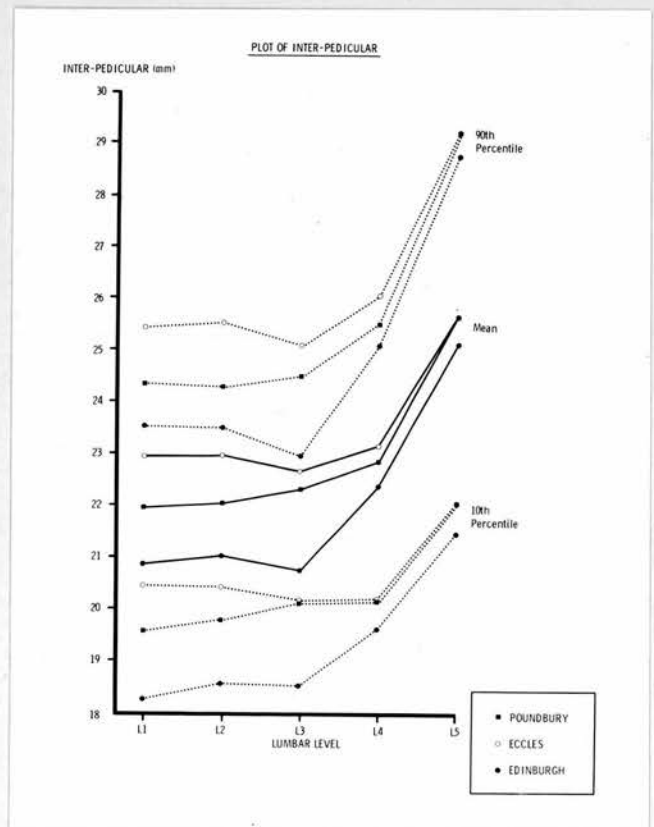


FIG. 31 GRAPH OF MEAN AND PERCENTILE INTERPEDICULAR DIAMETER FOR THREE SKELETAL POPULATIONS



PART 4. Section 12

FIG. 32 GRAPH OF MEAN AND PERCENTILE AREA FOR THREE SKELETAL POPULATIONS.

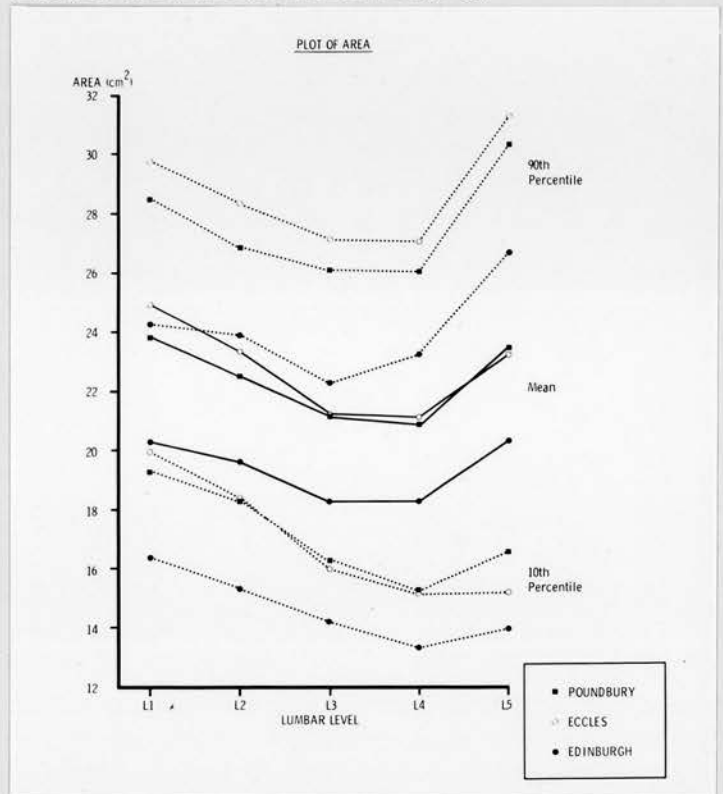
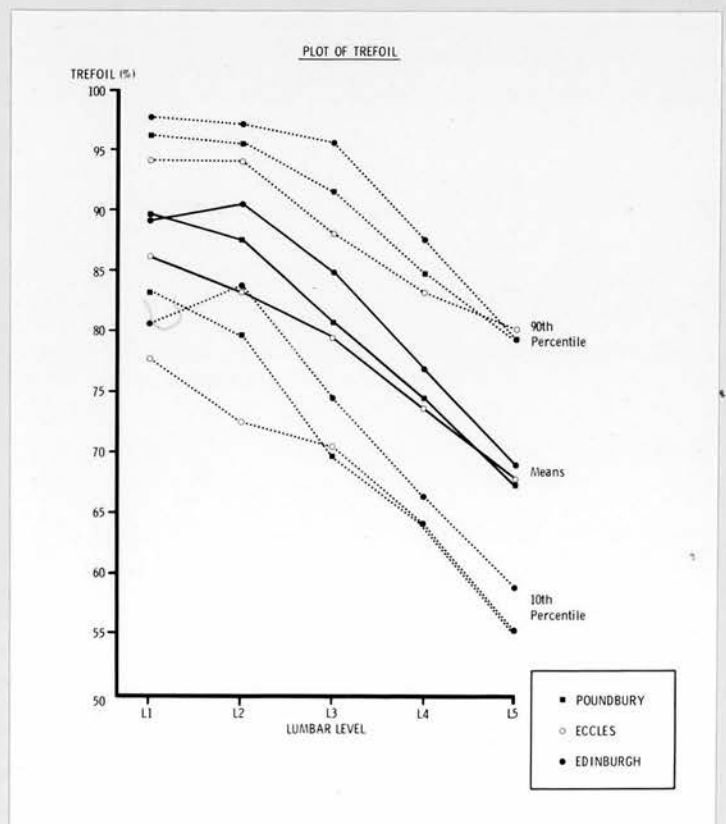


FIG. 33 GRAPH OF MEAN AND PERCENTILE DEGREE OF 'TREFOILNESS' FOR THREE SKELETAL POPULATIONS



PART 4. Section 12

The same general trends were present in each population. The Poundbury and Eccles collections showed a closer correlation than the Edinburgh spines. The two archaeological collections had a greater comparative homogeneity than the Edinburgh spines. It suggests that there is a possibility of racial variations in the anatomy of the spinal canal which could be of significance when considering the epidemiology of back pain.

I) THE TREFOIL CONFIGURATION

There is a gradual change in shape from the upper to the lower lumbar spine, from oval to triangular and then to the trefoil shape. The variation at each lumbar level is, however, considerable. The trefoil shape which is more common at L.5 has attracted special interest, because it places the neural elements at risk (Rothman 1972).

Baddeley (1976) noted that three of twenty eight Anglo-Saxon spines were trefoil at L.5. Eisenstein (1980) found that fourteen percent of 485 South African spines were trefoil at L.5 and a few also at L.4. Neither authors expressed the degree of trefoilness quantitatively.

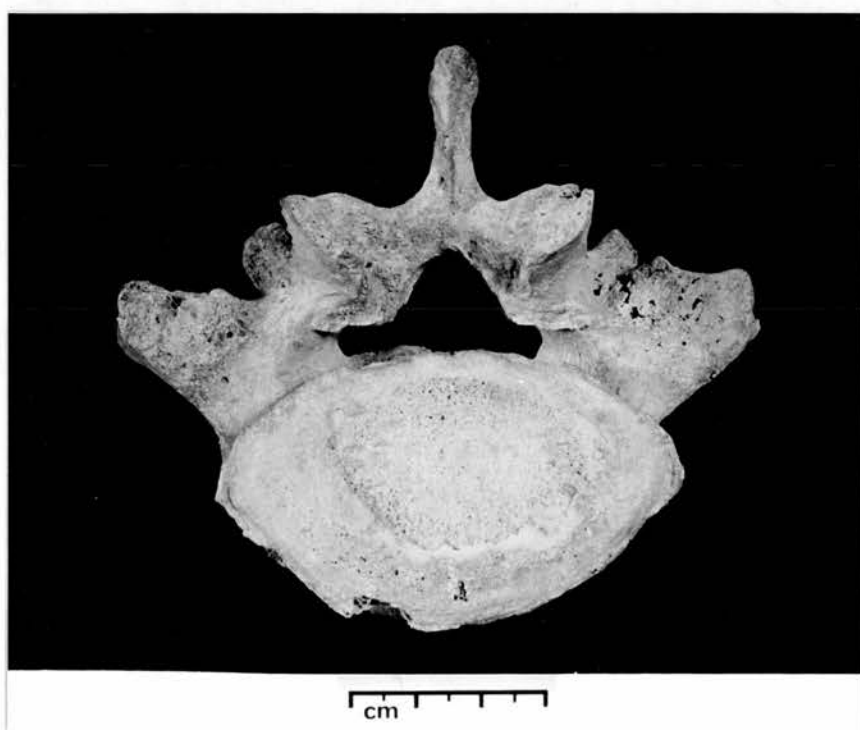
The measure of trefoilness from these three skeletal populations, from the ratio of two transverse diameters, indicates that there is a gradual change in shape of the canal throughout the lumbar spine, with the same range of variation at each level, Fig. 33. The three populations are almost identical in trefoil measurement. Figs. 34 and 35 show variations in the shape of two canals at L.5.

PART 4. Section 12

FIG. 34 PHOTOGRAPH OF 'DOME-SHAPED' SPINAL
CANAL AT L.5



FIG. 35 PHOTOGRAPH OF TREFOIL-SHAPED SPINAL
CANAL AT L.5



PART 4. Section 12 There was a correlation between the trefoil shape at L.5 and L.4 of .381, (Table 10), that is the spines most trefoil at L.5 were also slightly trefoil at L.4.

TABLE 10. CORRELATION BETWEEN TREFOILNESS AT L.5
AND TREFOILNESS AT OTHER LUMBAR LEVELS.

	L.1	L.2	L.3	L.4
Correlation Coefficient	-.147	.047	.070	.381

2) OTHER VERTEBRAL MEASUREMENTS

Other anatomical features of the Poundbury lumbar vertebrae were measured to compare with the degree of trefoil configuration and with canal size.

Right and left facet angles were recorded (Fig. 36).

The Pedicle Height was measured with calipers (Fig. 36) and the interfacet distance between the lateral margins of the articular surface of the inferior facet. The pedicle height and interfacet distance were expressed as a product. The wedging of the body of L.5 was recorded by expressing the posterior and anterior vertical depth of the body as a ratio (Fig. 37).

The maximum osteophyte projection from the superior and inferior margins of the lumbar vertebral bodies was measured by calipers.

PART 4. Section 12 DIAGRAM OF VERTEBRAE TO SHOW VERTEBRAL MEASUREMENTS RECORDED.

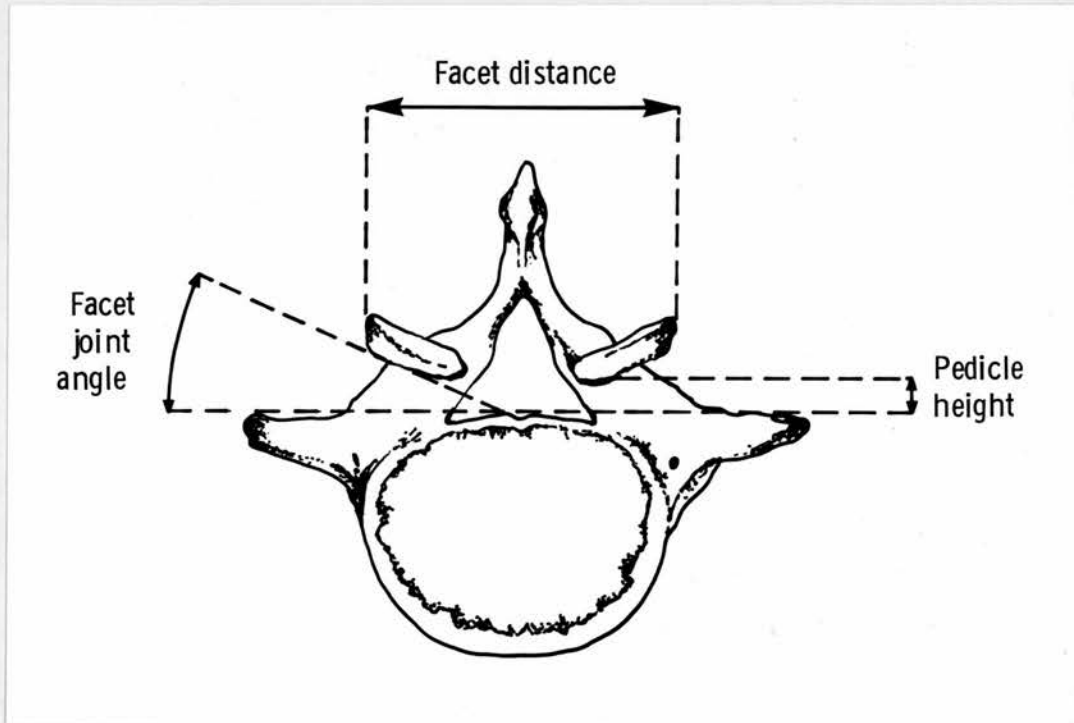


FIG.36

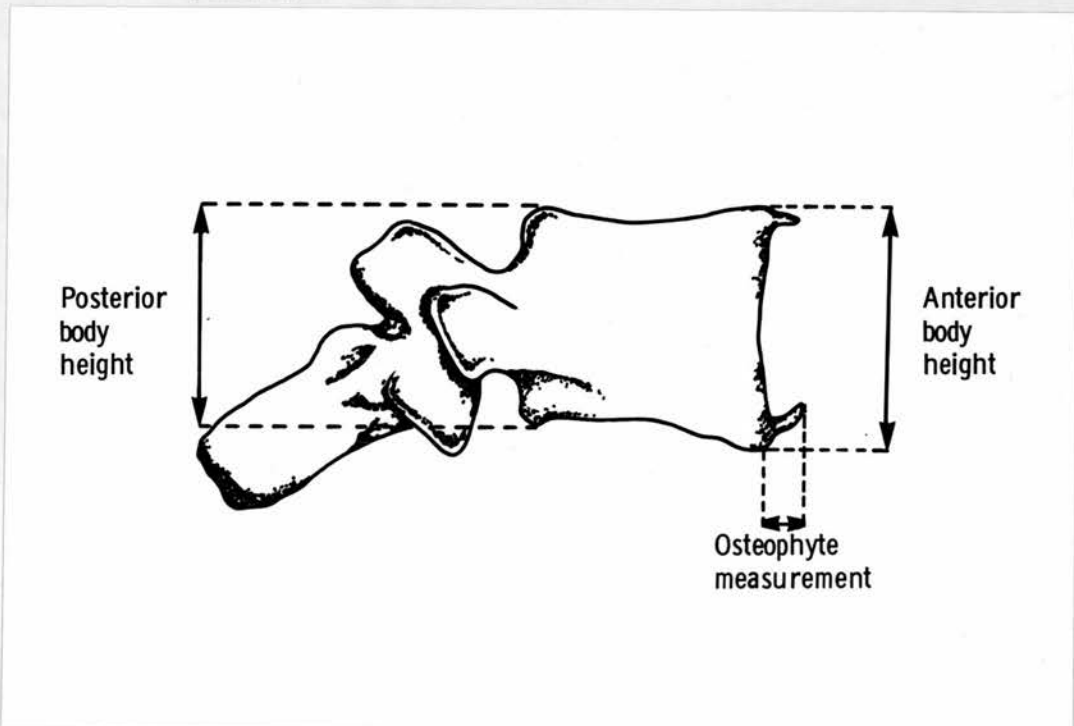


FIG.37

PART 4. Section 12 These vertebral measurements are recorded in Table II.

TABLE II. VERTEBRAL MEASUREMENTS FROM THE POUNDBURY SPINES

	Facet Angle	Pedicle Height Facet distance	Mean Canal Measurements for		Ratio of anterior posterior body
			Spines with NO Degen. Change	Spines WITH Degen. Change.	
Numbers measured	93	81	32	48	86
L.1	66.5 \pm 13.3	2.52 \pm 0.32	1.51 \pm 0.11	1.47 \pm 0.16	
L.2	61.3 6.8	2.84 0.66	1.44 0.14	1.42 0.18	
L.3	54.4 10.0	3.50 0.13	1.36 0.20	1.35 0.11	
L.4	41.5 10.8	4.30 1.20	1.34 0.19	1.31 0.07	
L.5	38.8 7.4	5.6 1.20	1.40 0.19	1.36 0.20	83.5 8.37

Baddeley (1976) noted a relationship between the trefoil shaped canal and vertebrae where the pedicle height was small and the facet joints close together. In this series there was a correlation of .35 ($p < .05$) Table 12. This is insufficient to be able to predict the canal shape from radiological measurement of the facet joints and pedicle height.

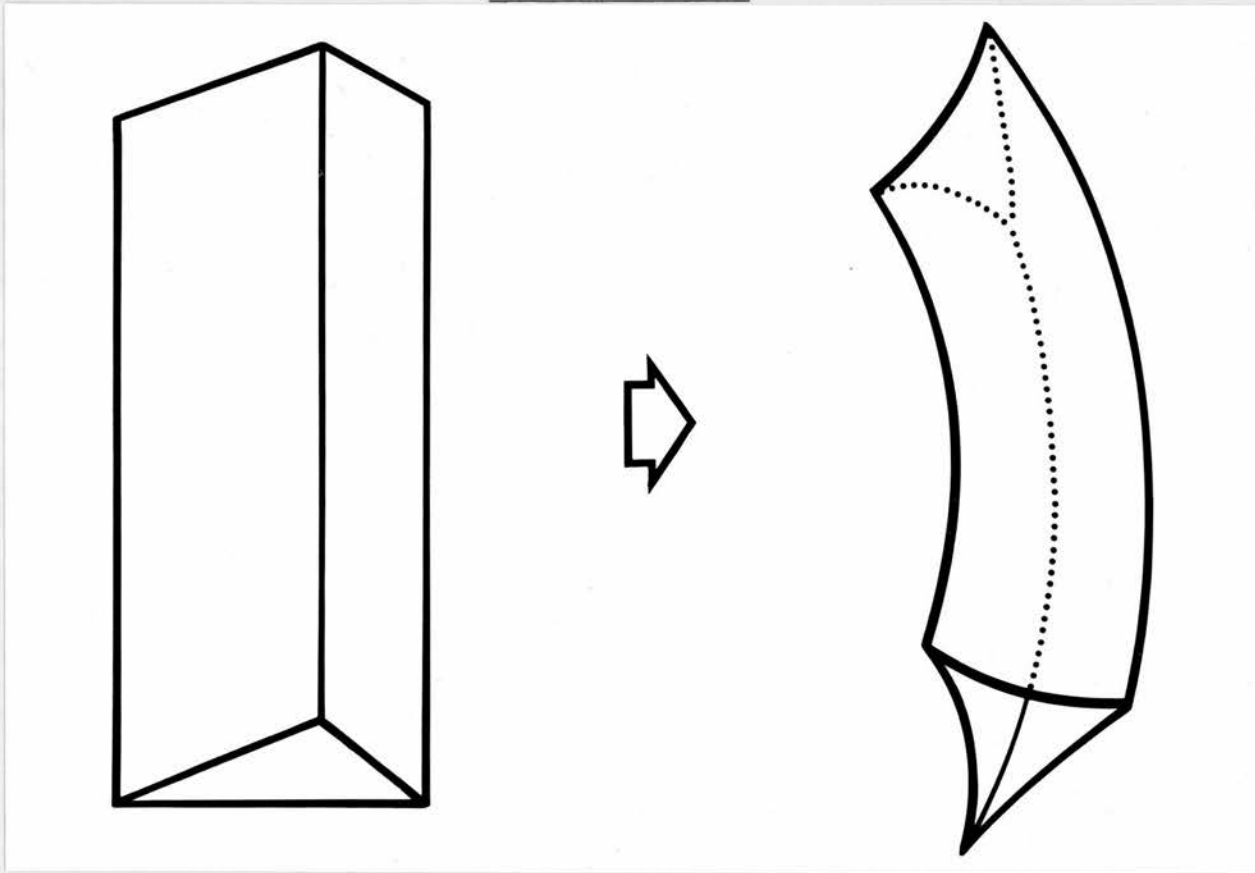
PART 4. Section 12

TABLE 12. CORRELATION COEFFICIENT BETWEEN TREFOILNESS AND OTHER VERTEBRAL MEASUREMENTS

	Facet Angle	Pedicle Height x Facetal Distance	Wedging at L.5	Inferior Degenerative Change	Superior Degenerative Change
"Trefoilness"	0.04	0.35	0.50	-.021	.0033

There was a correlation of .50 ($p < .05$) with trefoilness and vertebral wedging at L.5. Some spines were markedly trefoil at L.5 with no wedging, whilst others were wedged and not trefoil. Thus it cannot be assumed that because a spine has an acute lumbo-sacral angle on lateral X-ray, that the canal is trefoil. The correlation does suggest, however, that a factor in the development of the trefoil shape, is an acute lumbo-sacral angle.

Limborgh (1972), described how the local environmental factors of muscle forces and local external pressure can affect the growth of the skull vault. It is not improbable that the growth of the neural arch is also influenced by local environmental forces. If a pliable triangular tube is gradually bent, it assumes a trefoil shape. It is possible that mechanical forces associated with lumbar lordosis are a factor in encouraging the developing spine to adopt a trefoil configuration, (Fig.38).



The facet joints of the lower lumbar spine have a more horizontal orientation than those of the upper lumbar spine. This again is a gradual change with a similar range of variation at each level, (Table II). Hukins (1980) has recently shown that it is rotatory forces that are liable to damage the annulus fibrosus of the intervertebral disc rather than compressive forces. An appreciation of the degree of rotation permitted by the lower lumbar facet joints may become significant when considering constitutional factors of disc disease.

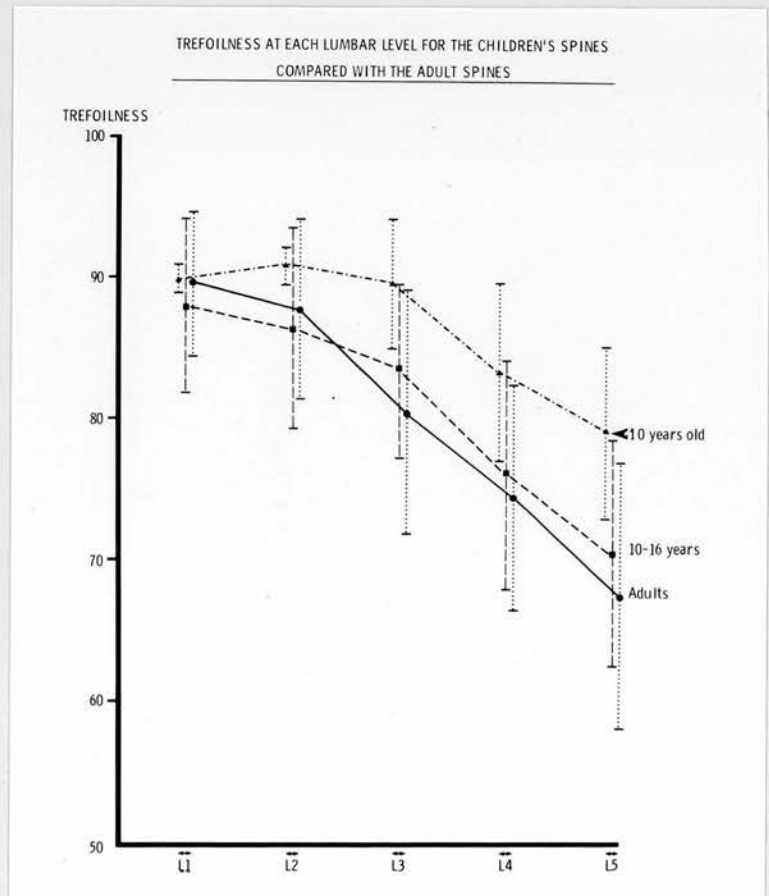
PART 4. Section 12 Epstein et al (1962) stated that vertical orientation of the facet joints was related to a shallow lateral recess, and a trefoil shaped canal. However, the skeletal measurements have not supported this, with a correlation of only .04 between the facet angle and the degree of trefoilness, (Table 12).

The Poundbury spines with degenerative change were slightly narrower in the fifteen degree oblique diameter than those without degenerative change, (Table II). It is probable that this is an age-related narrowing however, with the older spines demonstrating some degenerative change. There was a correlation of only -.02 between trefoilness at L.5 and degenerative change (Table 12), supporting Eisenstein's view (1980) that the trefoil configuration should be considered developmental and not the result of degenerative change.

PART 4. Section 12

There is a lack of information in the literature about the anatomy of the spinal canal in children (Bowen et al 1978). It is of interest that the trefoil shape was absent in the spines of the seven children under the age of 10 years, when the mean degree of 'trefoiliness' at L.5 was $79\% \pm 6\%$. There were some trefoil canals at L.5 in the children's spines between ten years and puberty, $71\% \pm 7\%$ compared with the 'trefoiliness' in the adult spines at L.5 of $67\% \pm 10\%$ (Fig. 39). The number of children's spines are small, but the evidence from these spines with the increasing degree of 'trefoiliness' with age, and the greater range, suggests that the trefoil shape develops in late childhood. There could be a relationship between the 'trefoiliness' and the development of the secondary curve of lumbar lordosis.

FIG. 39 GRAPH TO SHOW RANGE OF "TREFOILINESS" IN CHILDRENS' SPINES.



PART 4. Section 12

3) FIFTEEN DEGREE OBLIQUE SAGITTAL DIAMETER

The lumbar canal measurements in vivo by ultrasound is greater by one or two millimeters than the fifteen degree oblique measurement of the three skeletal populations, Table 13. It is interesting that this was noted in the two cadaveric specimens examined in Section 4, and it has already been noted that the photographic and ultrasound measurements are not necessarily measuring the canal at the same place. The photographic measurement is the minimum measurement in the fifteen degree oblique sagittal plane limited by the amount of light traversing the canal. Measurements were made to the mid point of the posterior surface of the vertebral body, which is not necessarily the point of measurement by ultrasound.

It has not been possible to estimate the chronological age of the three skeletal populations with any degree of accuracy, but the degree of degenerative change in all three collections suggests that many had lived into late adult life. They are therefore comparable with the ultrasound measurements recorded from the older adults. The difference between the mean measurements of the three populations is of note. Eisenstein (1977) found a slight but significant variation between canal measurements in caucasoid and negro spines. Canal measurements should indeed be a factor to consider when studying the racial incidence of back pain.

PART 4. Section 12

TABLE 13. MEAN FIFTEEN DEGREE OBLIQUE SAGITTAL MEASUREMENTS FROM THE THREE SKELETAL POPULATIONS, COMPARED WITH MEAN ULTRASOUND MEASUREMENTS FROM FIFTY TO SIXTY FIVE-YEAR-OLD SUBJECTS

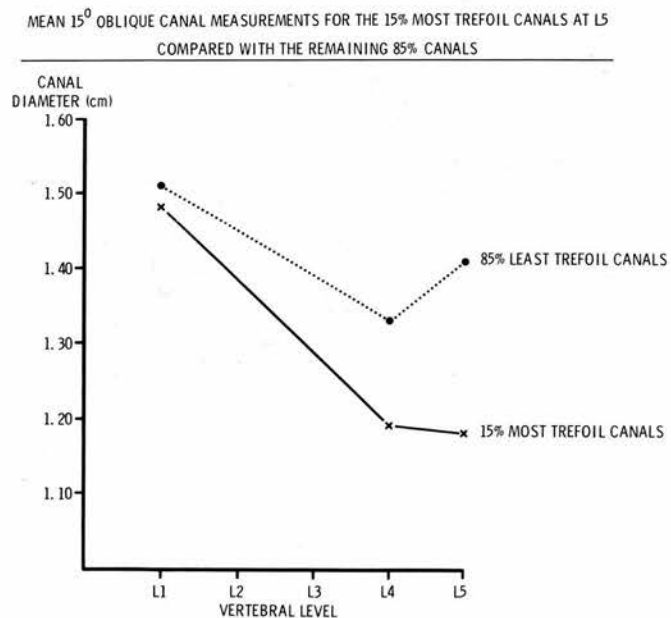
MEAN PHOTOGRAPHIC MEASUREMENTS OF 15° OBLIQUE SAGITTAL DIAMETER (cms).					
	L.1	L.2	L.3	L.4	L.5
Poundbury Spines	1.50	1.41	1.34	1.32	1.39
Eccles Spines	1.52	1.46	1.37	1.36	1.40
Edinburgh Spines	1.40	1.33	1.24	1.23	1.26

MEAN ULTRASOUND MEASUREMENTS OF 15° OBLIQUE SAGITTAL DIAMETER (cms).					
	L.1	L.2	L.3	L.4	L.5
15-18 years of age	1.66	1.62	1.59	1.55	1.57
50-65 years of age	1.55	1.52	1.48	1.45	1.47

The mean pattern of measurement from L.1 to L.5 was the same for the measurements by ultrasound in vivo and for the fifteen degree oblique diameter of the three skeletal populations, being widest at L.1 reducing by one to two millimeters at L.4 and widening by less than a millimeter at L.5.

PART 4. Section 12. The pattern of 15° oblique measurement was examined in those skeletons with the most marked degree of 'trefoilness'. Fifteen per cent of the vertebrae were trefoil at L.5 (to a degree of 57% or less). Their pattern of measurement was compared with the eighty five per cent of the spines where L.5 was not trefoil (greater than 57% trefoil measurement). The reduction in measurement from L.1 to L.4 was significantly greater when L.5 was trefoil, and in addition, L.5 tended to be equal or less than L.4 (Fig. 40).

FIG.40 GRAPH OF MEAN FIFTEEN DEGREE OBLIQUE MEASUREMENT OF THOSE VERTEBRAE WITH THE MOST DEGREE OF 'TREFOILNESS' (LESS THAN 57%), COMPARED WITH THE MEAN FIFTEEN DEGREE MEASUREMENT OF THE REMAINING VERTEBRAE.

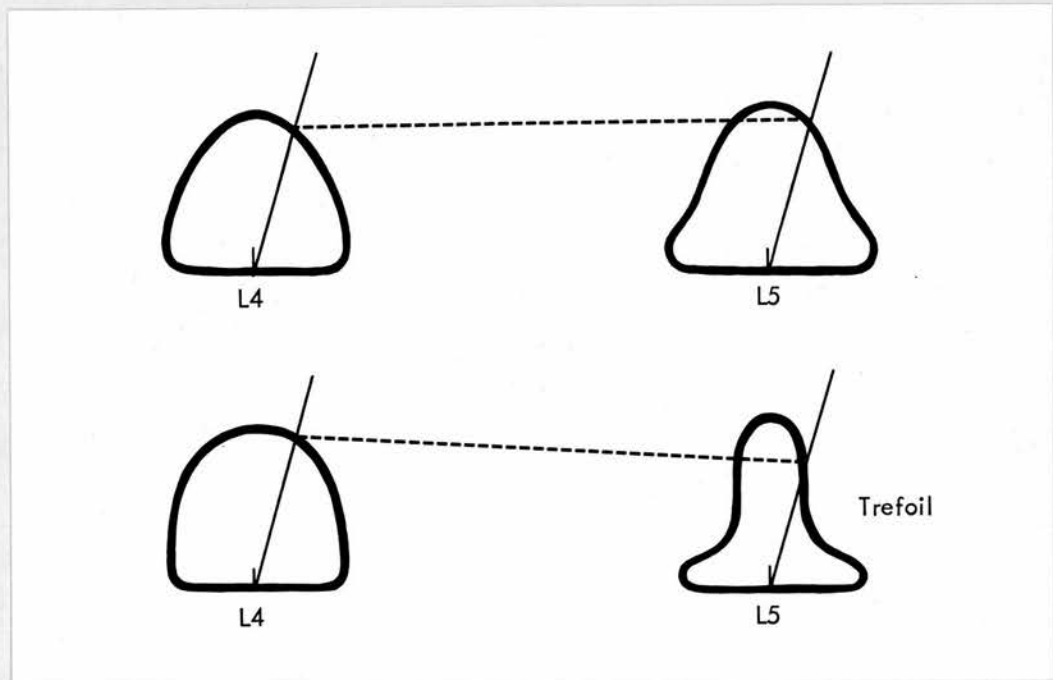


PART 4. Section 12

The trefoil shape will be reflected in the reduction of the oblique diameter provided that the mid sagittal diameter does not increase disproportionately at the lower lumbar levels.

This observation in the pattern of measurement of the fifteen degree oblique diameter in the trefoil spines has clinical significance. When the ultrasound measurements in vivo present a marked reduction in size from L.1 to L.4, and when L.5 is also equal or less than L.4, the trefoil shape should be suspected. (Fig. 4I)

FIG.4I DIAGRAM TO SHOW HOW THE MEASUREMENTS OF THE FIFTEEN DEGREE OBLIQUE DIAMETER CAN BE LESS AT L.5 THAN L.4 IN THE PRESENCE OF A TREFOIL-SHAPED CANAL.



PART 5

ULTRASOUND MEASUREMENTS OF THE LUMBAR SPINAL
CANAL IN OVER SEVEN HUNDRED PATIENTS WITH BACK
AND/OR LEG PAIN.

PART 5.

ULTRASOUND MEASUREMENTS OF THE LUMBAR SPINAL
CANAL IN PATIENTS WITH BACK AND/OR LEG PAIN.

PART 5. Section 13.

Measurements from Patients with Lower Lumbar Disc
Lesions

Following the description by Mixter and Barr (1934) of the syndrome of the ruptured lumbar intervertebral disc, Clinicians have shown more interest in the size of the disc lesion than in the available space within the spinal canal. It has been increasingly recognised that a disc protrusion or herniation can compromise an already narrow canal (Paine and Haung 1972, Williams 1975, Choudhury and Taylor 1977, McCulloch 1977, Verbiest 1977). The relative importance of the canal size in the symptomatology of the acute disc lesions has not been established however because of difficulty in obtaining accurate measurement. Measurement of the oblique sagittal diameter of the spinal canal by ultrasound provides opportunity to assess the significance of the canal diameter in the presence of disc symptoms.

Ultrasound measurements were obtained from 151 patients under the age of 45 years, who were considered to have symptoms associated with a lower lumbar disc lesion. They fulfilled two of the following three criteria.

PART 5. Section 13.

- 1) Unilateral leg pain in a nerve root distribution, extending below the knee, and worse in the leg than in the back.
- 2) Straight leg raising less than 50° .
- 3) Two of four abnormal neurological signs; diminished reflex, sensory loss, muscle weakness, muscle wasting.

Their average age was 37 years, and 66% were male. Their mean measurements are shown in Fig. 42 and are compared with the tenth percentile for young people. The measurements at L.5 are shown in Fig. 43, comparing the number of patients with the percentiles of young people. 56% are below the tenth percentile.

PART 5. Section 13.

FIG. 42. GRAPH OF MEAN ULTRASOUND MEASUREMENTS FOR PATIENTS WITH DISC SYMPTOMS, COMPARED WITH 10TH PERCENTILE OF 15-21 YEAR OLD SUBJECTS.

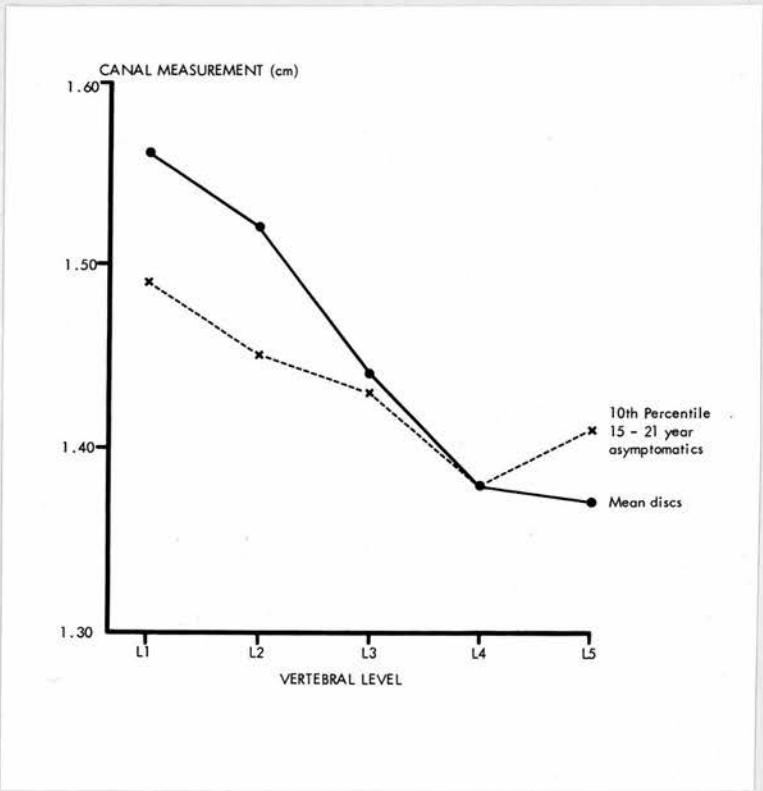
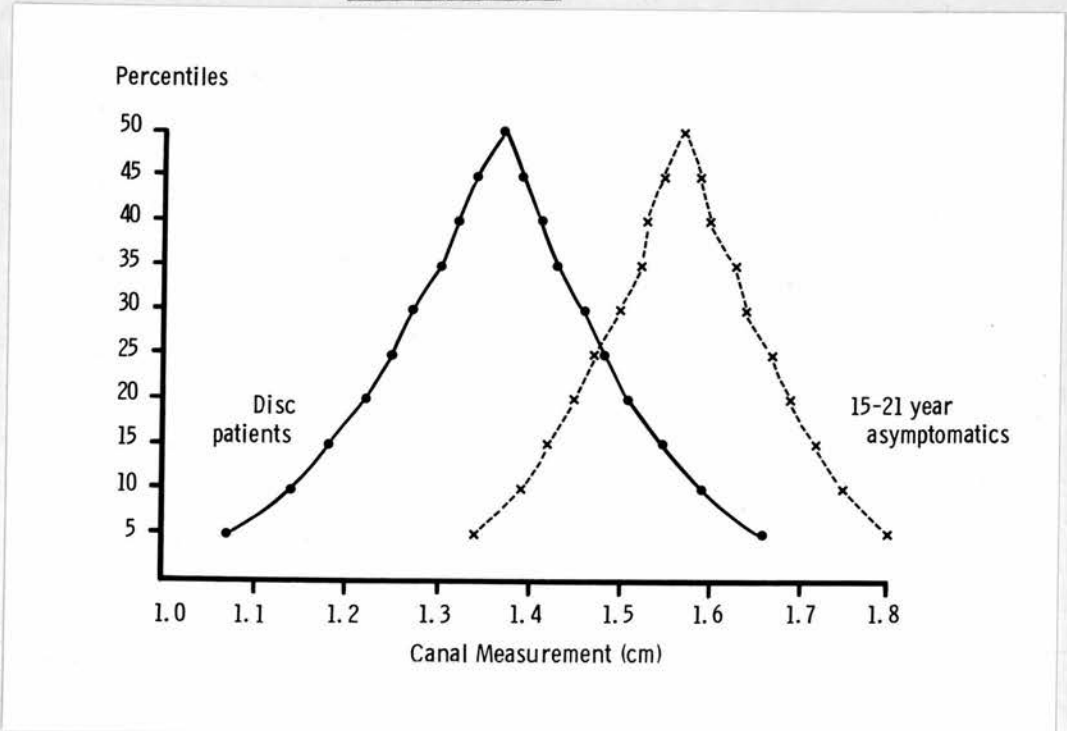


FIG. 43. PERCENTILE ULTRASOUND MEASUREMENTS AT L.5 FOR 151 PATIENTS WITH DISC SYMPTOMS, COMPARED WITH PERCENTILES FOR 15-21 YEAR OLD SUBJECTS .



PART 5. Section 13

A comparison was made between canal size and response to treatment (Table 14). 63 patients whose symptoms settled at home had a mean diameter of 1.40 cm. at the fifth lumbar level, 55 patients who responded to in-patient traction had a mean diameter at L.5 of 1.37 cm, whilst 33 patients who required surgery had a mean diameter of 1.32 cm.

TABLE 14. MEAN CANAL SIZE FOR 151 PATIENTS WITH DISC SYMPTOMS
RELATED TO RESPONSE TO TREATMENT

	Settled at home	In-Patient Traction	Required Surgery
Number	63	55	33
L.1	1.58	1.56	1.54
L.2	1.55	1.51	1.50
L.3	1.46	1.45	1.43
L.4	1.42	1.36	1.35
L.5	1.40	1.37	1.32

These measurements suggest that the available space in the spinal canal is highly significant in the symptomatology of disc lesions. The fact that 56% of the patients with disabling disc symptoms have measurements below the tenth percentile of asymptomatic subjects, suggests that many patients with wider canals escape disc symptoms in the presence of disc prolapse. It is probable that disc pathology is unrelated to the size of the spinal canal, but that the development of symptoms is inversely related to the canal size. Patients with measurements less than 1.4 cm at the

PART 5. Section 13

fourth and fifth lumbar levels are at risk. The probability of failure to respond to treatment is also related to the size of the canal. The narrowest canals were recorded in those patients who required surgical treatment.

Lumbar nerve roots will be most vulnerable to compression in a narrow canal that is also of trefoil shape (Section 12). The mean measurements for the 151 patients with disc symptoms, with L.5 less than L.4 and a steep drop in measurements from L.1 to L.4 suggests that many of these canals are also trefoil in shape.

SURGICAL SIGNIFICANCE

The high incidence of narrowing of the central canal in the presence of disc symptoms has not been generally recognised, and it may account for some of the poor results of operation. It is difficult to appreciate the dimensions of the spinal canal when it is examined through the usual limited exposure. Naylor (1974) records a continuation of some symptoms in 62 per cent of patients after operation for disc prolapse, and Gurdjian et al (1961) in 71 per cent. Verbiest (1977) exploring and measuring the canal at several levels with his 'stenosimeter' reported surgical failures from previous operations due to an unrecognised stenosis in the presence of disc protrusions.

PART 5. Section 13

The results of disc surgery are more favourable when a frankly herniated nucleus pulposus is removed, rather than excision of a 'bulging' disc (Hirsch and Nachemson 1963) (Nachemson 1976), but perhaps the significance of the proportional difference between the size of the disc protrusion and the available space has not been adequately appreciated.

Some surgeons have recommended routine decompression of the spinal canal when removing a herniated or ruptured intervertebral disc, (Paine and Haung 1972, and Shenkin and Hash 1976), but measurement of the spinal canal before operation would be a more rational approach to surgical treatment. In the presence of a 1.2 cm canal and a small protrusion, it would be unreasonable to enucleate the disc through a small fenestration and risk subsequent stenotic symptoms. Decompression would be a more reasonable procedure, and might perhaps be necessary at more than one level. The larger sequestration, however, in a wider canal, can be readily treated by removal of the extruded nucleus alone.

PART 5. Section 14.

MEASUREMENTS FROM PATIENTS WITH ROOT ENTRAPMENT SYNDROME

The root canal is that part of the spinal canal containing the lumbar nerve root where the root leaves the cauda equina and passes inferior to the pedicle towards the intervertebral foramen.

Its relations are:-

- | | |
|-----------|---|
| Superior | The pedicle which is first supero-lateral and then superior. |
| Posterior | The lateral part of the lamina where it joints the inferior articular process in the region of the pars interarticularis. The edge of the inferior facet, the facet joint and the superior articular process of the vertebra below. |
| Inferior | The superior vertebral notch formed by the pedicle of the vertebra below. |
| Anterior | The posterior surface of the vertebral body, the intervertebral disc, and the superior aspect of the posterior surface of the vertebra below at the intervertebral foramen. |

Thus the nerve in the root canal is vulnerable to compression, tethering, traction and irritation from the mechanical involvement of many structures (McCulloch 1977)

Fig. 44.

PART 5. Section 14

FIG.44. POUNDBURY L.5 VERTEBRA WITH OSTEOPHYTE
IN THE LEFT ROOT CANAL. TYPE OF LESION
WHICH COULD CAUSE "ROOT ENTRAPMENT
SYNDROME". NOTE CENTRAL CANAL IS NOT
TREFOIL.



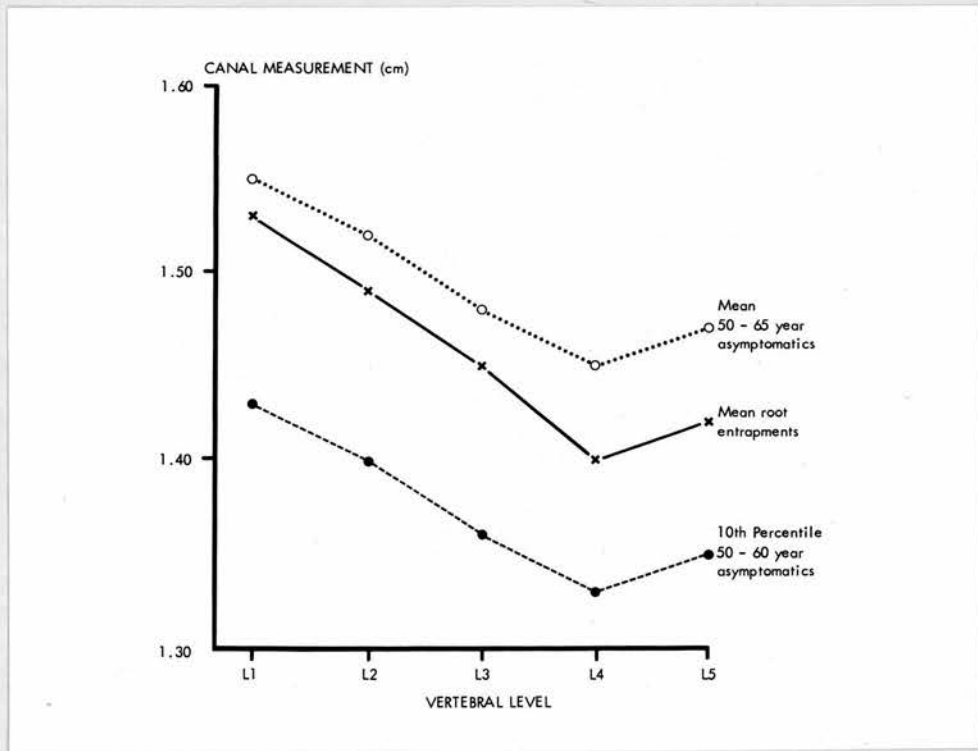
78 patients over the age of 45 years were considered to have root entrapment syndrome, with pathology involving the nerve root in the root canal. They had unilateral leg pain in a nerve root distribution, from the buttock to the ankle. Back pain was absent or minimal. The leg pain was severe and constant, often making them pace the floor at night. It was not relieved by recumbancy. Abnormal signs were few. Back extension was frequently limited and there was often some lower lumbar tenderness. Straight leg raising was usually full or only slightly restricted, and

PART 5. Section 14

neurological signs were normal.

Measurements from the 78 patients with root entrapment syndrome are compared with the mean and tenth percentile of the older subjects (Fig.45). The average age was 56 years. 52% were male.

FIG. 45 GRAPH OF MEAN ULTRASOUND MEASUREMENTS
FOR PATIENTS WITH ROOT ENTRAPMENT
SYNDROME, COMPARED WITH MEAN AND
TENTH PERCENTILE FOR FIFTY TO SIXTY-FIVE
YEAR OLD SUBJECTS.

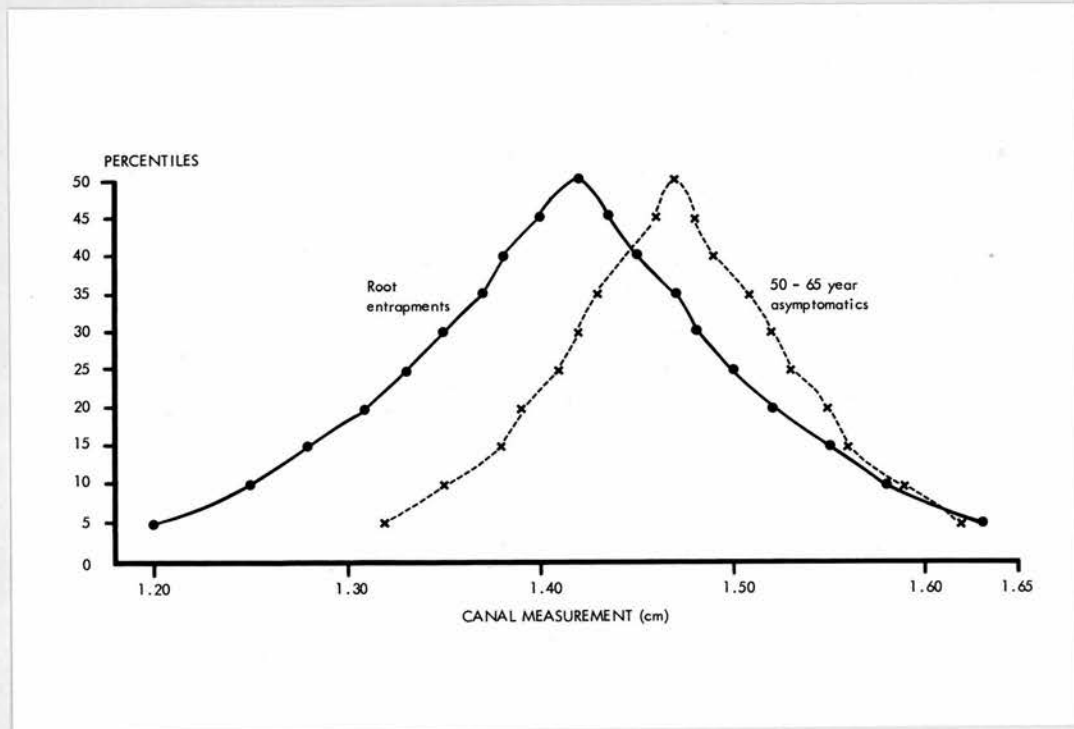


PART 5. Section 14

The central canal only is measured by ultrasound, but 30% of 78 patients diagnosed as root entrapment syndrome had canals below the tenth percentile of the 50-65 year old miners, nurses and sedentary workers (Fig. 46).

This can be alternatively expressed as a subject with central canal measurement below the tenth percentile being four times more likely to have root entrapment syndrome than the rest of the population.

FIG.46. PERCENTILE ULTRASOUND MEASUREMENTS AT L.5 FOR 78 PATIENTS WITH ROOT ENTRAPMENT SYNDROME, COMPARED WITH PERCENTILES FOR 50-65 YEAR OLD SUBJECTS.



PART 5. Section 14.

Krayenbuhl and Benini suggested that root entrapment was more likely to occur in the spine with a small lateral recess (1979). The ultrasound measurements however do not show that patients with root entrapment syndrome have a particularly narrow central canal, nor that they are generally trefoil in shape with narrow lateral recesses. Their pattern of measurement from L.1 to L.5 is similar to the general population, as distinct from the patients with disc lesions and neurogenic claudication (Figs. 42 and 47).

It is thus probable that pathology in the root canal is more likely to cause symptoms if the central canal is also narrow, but many patients with root entrapment syndrome do have an adequate central canal measurement. The pathological cause for these patients symptoms is not restriction of space in the central canal.

PART 5. Section 15

MEASUREMENTS FROM PATIENTS WITH SYMPTOMS OF
NEUROGENIC CLAUDICATION.

Symptoms of neurogenic claudication which are now accepted as classical evidence of spinal stenosis were first described by Verbiest (1954). He described "tiredness and loss of power in both legs, anaesthesia, a feeling of numbness in some lumbo-sacral dermatomes, or bilateral sciatica. The signs appeared only during walking, standing or heavy bodily exertion. They disappeared immediately at rest".

Several surgeons had previously reported symptomatic relief from leg symptoms by lumbar laminectomy, from Sachs and Frenkel in 1899 to Towme and Reichert in 1931. Sarpyener in 1945 described deformities, paraplegia and enuresis in children associated with a narrow lumbar spinal canal, but neurogenic claudication was first recorded by Verbiest.

Verbiest in 1955 described the relative importance of soft tissue and bony encroachment, affecting an already narrow canal, to produce claudication symptoms. Narrowing of the bony canal has not been universally accepted as the main factor in neurogenic claudication, however. The importance of soft tissue compressing the cauda equina has not been resolved. It is possible to have a large space occupying lesion in the form of a slowly growing tumour within the spinal canal not causing claudication symptoms. Some therefore attribute the lesion not to the central canal

PART 5. Section 15. but to the root canal and foramen (Domminisse 1975 and Naylor 1978).

In the hope of resolving the relative importance of the size of the central canal, measurements were obtained by ultrasound from 138 patients with classical symptoms of neurogenic claudication. Symptoms involved both legs in a generalised rather than in a root distribution, and were aggravated by walking and relieved by rest. Abnormal signs were few, and the peripheral circulation was normal.

There were many variations of the pattern of claudication. Some patients had symptoms constantly in the legs which were aggravated by walking. Others developed symptoms only when walking. Some had identical symptoms waking them at night. Spinal extension appeared to precipitate symptoms in some patients (Salibi 1976), making walking down a slope difficult, and sleeping on the face impossible. Walking up a slope was less troublesome and cycling (Dyck and Doyle 1977) and climbing ladders often no problem. Other patients did not recognise difficulty when performing activities with the spine extended. Some had symptoms around the knees only whilst others were troubled with discomfort from the buttocks to the feet. Some had night cramps. Some had symptoms in the legs only, others had associated back pain. Patients were included in the series who admitted some of these symptoms in both legs, which were aggravated by walking and relieved by rest, and whose peripheral arterial pulses were palpable.

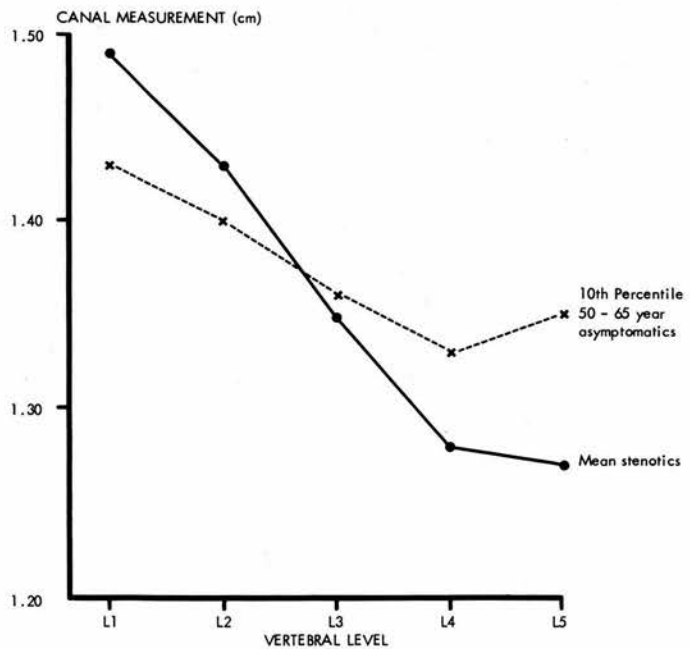
PART 5. Section 15

There were 138 patients with symptoms of neurogenic claudication. The average age was 48.8 years. 73.2% were male, and 46% were miners. The mean duration of back or leg symptoms before measurement was 7.2 years.

69% of these patients had measurements at L5 less than the tenth percentile for the older adults (that is the 332 subjects between 50 and 65 years of age), Fig. 47.

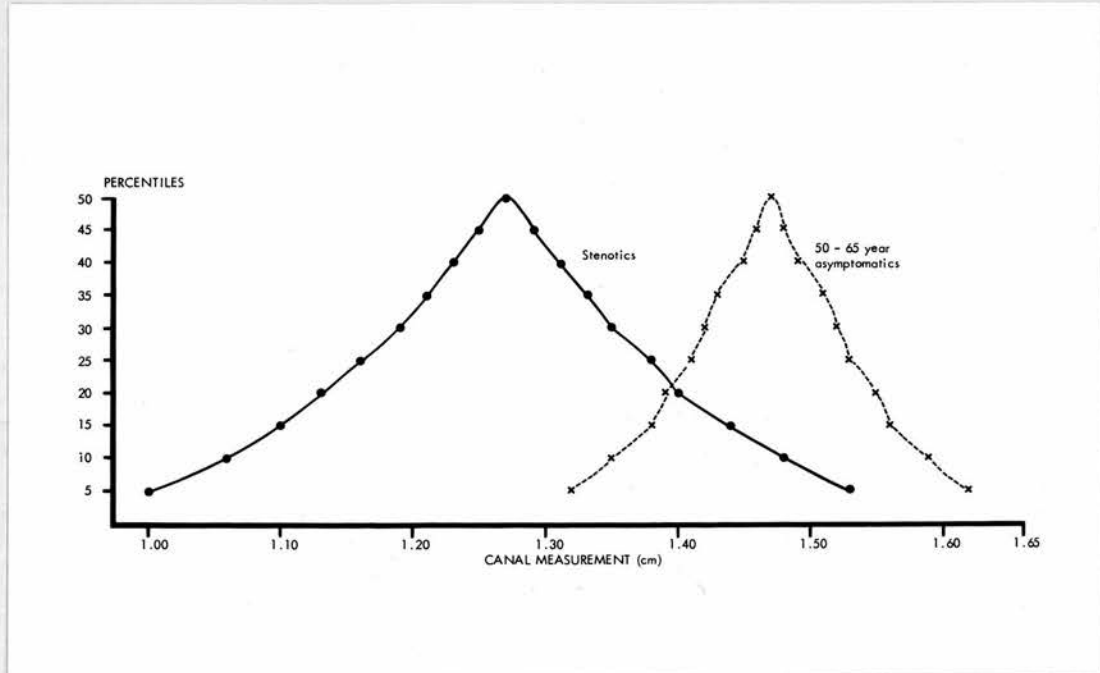
The percentiles at L5 are shown in Fig. 48.

FIG. 47 GRAPH OF MEAN ULTRASOUND MEASUREMENTS
FOR PATIENTS WITH NEUROGENIC CLAUDICATION
COMPARED WITH 10TH PERCENTILE FOR
50-65 YEAR OLD SUBJECTS.



PART 5. Section 15

FIG.48 PERCENTILE ULTRASOUND MEASUREMENTS AT L.5 FOR 138 PATIENTS WITH NEUROGENIC CLAUDICATION, COMPARED WITH PERCENTILES FOR 50-65 YEAR OLD SUBJECTS.



AETIOLOGICAL IMPLICATIONS

Measurement indicates that the size of the central canal is highly significant in the majority of patients who develop neurogenic claudication.

Not all patients with a narrow canal develop claudication symptoms however, and presumably many of the patients with claudication have had a narrow canal for many years of their adult life without symptoms. It is probable that

PART 5. Section 15

there is an added factor in addition to the narrow bony canal that is responsible for symptoms.

FACTORS THAT COULD CAUSE NARROWING OF THE CENTRAL SPINAL CANAL IN ADDITION TO BONY NARROWING.

Anteriorly

Transverse vertebral bars at inferior border of vertebra above and superior border of vertebra below.

Bulging disc protrusion. Previous disc herniation.

Scar tissue associated with previous disc pathology.

Scar tissue associated with previous disc surgery.

Posteriorly

Thickened or buckling ligamentum flavum (Paine and Haung 1972).

Cephaled edge of the lamina.

Osteophytes in the ligamentum flavum extending from the superior attachment to the anterior surface of the lamina.

Laterally

Bony encroachment from the facet joints (Choudhury and Taylor 1976).

Capsular thickening at the facet joints (Harris and MacNab 1954).

Synovial thickening.

PART 5. Section 15

1) LAMINA THICKENING

There have been many reports of surgery for patients with spinal stenosis having lamina thicker than normal, (Friedmann 1961, Epstein et al 1962, Schatzker and Pennal 1968 and Ehni 1969). If it is assumed that heavy manual work is responsible for this lamina thickening and stenosis, this cannot be supported from the ultrasound measurements of the miners, nurses and sedentary workers (Section 9), where the sedentary workers were found to have the narrowest canals. Lamina thickening could occur on the posterior surface but the results from the miner's measurements suggests that this does not affect the size of the central canal. It is probable that some of the patients described in the literature with stenosis and lamina thickening already had developmentally narrow canals, and that lamina thickening was part of a more generalised vertebral degenerative change. The narrow canal should be considered to be developmental rather than degenerative, though superimposed degenerative change may be a precipitating factor in the symptomatology.

2) DISC SPACE NARROWING permits the vertebrae above and below to settle together causing some bulging of the disc material, and some buckling of the ligamentum flavum.

Associated degenerative change with the disc space narrowing can produce vertebral bars, and as the vertebral joints are a three joint system (Lewin et al 1962), the facet joints can develop degenerative change and thus bony encroachment.

PART 5. Section 15

The inferior facet joint of the vertebra above slides over the superior joint of the vertebra below often slightly tilting the vertebrae, and the shingling causes the caudal edge of the lower vertebral lamina to assume a more horizontal position, and to encroach into the canal (Chandnani and Chhabria 1978, and Krayenbuhl and Benini 1979).

3) PREVIOUS DISC SEQUESTRATION

At surgery sequestered disc material is occasionally found free in the spinal canal. It is probable that some patients have separated fragments of disc in the canal that have not caused enough symptoms for removal, but subsequently associated scar tissue compromises the canal.

4) SPONDYLOLYTIC SPONDYLOLISTHESIS can cause soft tissue and bony encroachment into the spinal canal at the region of the pars interarticularis, where fibrosis and bony thickening is associated with an attempted healing process.

5) DEGENERATIVE SPONDYLOLISTHESIS

Forward slipping of one vertebra, usually L.4/5 level, can produce narrowing of the canal and be associated with symptoms of neurogenic claudication (Rosenberg 1976).

PART 5. Section 15

Wilson (1977) found that 50% of his patients with neurogenic claudication had degenerative spondylolisthesis. It is generally agreed that forward slipping with an intact arch in degenerative spondylolisthesis is more likely to produce cauda equina symptoms than a slip with an attenuated arch or pars defect in spondylolytic spondylolisthesis.

6) INSTABILITY with unnatural movement at one vertebral level can effectively reduce the available space for the cauda equina.

There are, therefore, many possible additional factors that can compromise a canal that is already narrow, producing stenosis and claudication symptoms. The measurements obtained by ultrasound suggest that the narrowing of the central bony canal is the main underlying structural problem for the majority of patients.

46% of the patients with neurogenic claudication were miners, whilst only 8% of the population served by Doncaster Royal Infirmary are miners. There is no evidence to suggest that the central canal is narrowed by underground work (Section 8), but the stress to which the spine is subjected by heavy labouring work is probably responsible for the 'other factors' which will compromise an already narrow canal. Many subjects with a similarly narrow canal who have avoided gross mechanical strain

PART 5. Section 15. on the spine apparently escape neurogenic claudication.

The mean pattern of measurement for patients with neurogenic claudication shows a steep drop in measurement from L.1 to L.4 with L.5 less than L.4 (Fig. 47).

This same pattern is observed for the mean measurements of patients with disc symptoms (Fig. 42). This suggests that the canals for these two groups of patients are not only small in size, but also trefoil in shape (Section 12).

PART 5. Section 15

SURGICAL IMPLICATIONS

Ultrasound measurement of the spinal canal is a most useful diagnostic aid for the patient suspected of having spinal stenosis and claudication symptoms. Previously the diagnosis could be confirmed only by myelography, and this did not permit accurate measurement. The lack of space in the spinal canal made the investigation often difficult (Williams 1975). Computerised tomography can identify a bony stenosis and its extent (Postacchini et al 1980), but has the disadvantages of x-ray exposure and expense. Ultrasound offers an accurate measurement of the bony canal and can confirm the bony stenosis in degree and segmental extent. A knowledge of the extent of the stenosis is helpful to the surgeon who needs to know how far proximal to extend his decompression.

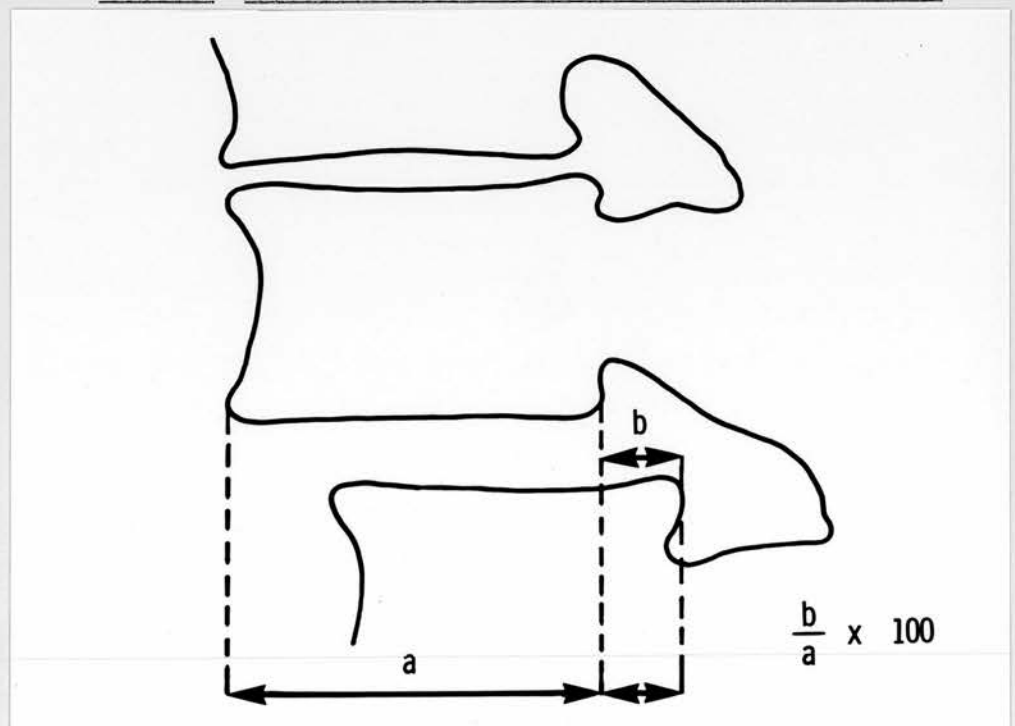
It has been the practice in the management of the patients in this series of 138 patients to measure the canal by ultrasound when the diagnosis is suspected. If the canal is particularly narrow (less than 1.3 cm at L.4 and L.5), and if surgical decompression is required clinically, surgery is carried out without a pre-operative myelogram. If the symptoms appear genuine and the ultrasound measurements are above 1.3 cm., radiculography is performed in the hope of identifying a lesion compromising the canal.

PART 5. Section 16. MEASUREMENTS FROM PATIENTS WITH SPONDYLOLISTHESIS

Symptoms of nerve root compression are more likely to occur in degenerative spondylolisthesis, with an intact neural arch, than in spondylolytic spondylolisthesis, (MacNab 1950, Newman 1963, Schatzker and Pennal 1968 and Wilson 1977). The degree of slip in degenerative spondylolisthesis is not related to the severity of the symptoms (Rosenberg 1976). The relationship between symptoms and canal size in both degenerative and spondylolytic spondylolisthesis has not been established. Measurements were obtained therefore from 148 patients with spondylolisthesis presenting to hospital with back pain. They were reclassified according to Wiltse, Newman and MacNab (1976), the majority being either spondylolytic or degenerative.

The degree of forward displacement was measured as a 'slip-ratio' from a lateral x-ray, expressing the forward slip of the vertebra above as a ratio of the antero-posterior diameter of its lower border, Fig. 49.

FIG. 49 DIAGRAM TO SHOW SLIP RATIO MEASUREMENT



PART 5. Section 16

The number of patients in each group, the age and sex distribution, the level of the lesion and the mean canal diameter is shown in Table 15.

TABLE 15. ULTRASOUND MEASUREMENTS FOR PATIENTS WITH SPONDYLOLYSIS AND SPONDYLOLISTHESIS

Group	Total	Sex Distribution		Level of Slip			Age	
		% male	% female	L.3/4	L.4/5	L.5/S.1	Mean and S.D.	Now Onset
Dysplastic Congenital 1	8 1.55 1.52 1.46 1.42 1.42	62.5	37.5	0	0	8	+32.4 -16.4	+27.7 -18.0
Isthmic Spondylo- lytic 2	72 1.55 1.51 1.47 1.44 1.45	67.1	32.9	1 1.63 1.62 1.59 1.57 1.55	8 1.58 1.55 1.53 1.51 1.52	63 1.54 1.50 1.46 1.43 1.44	39.6 + - 13.2	34.8 + - 13.1
Traumatic 3	2 1.51 1.51 1.45 1.42 1.51	100	0	0	1 1.45 1.45 1.40 1.34 1.33	1 1.56 1.56 1.50 1.50 1.68	61.0 + - 5.7	57.2 + - 11.0
Degen- erative 4	66 1.50 1.47 1.44 1.41 1.40	32.4	67.7	10 1.45 1.43 1.40 1.38 1.38	38 1.51 1.48 1.43 1.41 1.40	18 1.51 1.48 1.46 1.44 1.43	61.4 + - 10.2	52.7 + - 16.0

PART 5. Section 16 Comparisons between the slip-ratio and the canal size at L.5 and L.4 are shown in Table 16 for spondylolytic and degenerative spondylolisthesis. (There were insufficient patients with congenital and traumatic spondylolisthesis for significant conclusions). The Table also records the mean canal diameter for those patients with a slip greater than the mean, and for those with a slip less than the mean.

TABLE 16. COMPARISONS BETWEEN THE SLIP-RATIO AND CANAL SIZE.

	Spondylolytic Spondylolisthesis	Degenerative Spondylolisthesis
Total	63	53
Correlation Coefficient of Canal Diameter against Slip Ratio	Level of Slip .043	Level of above Slip -.082
Slip Ratio Mean S.D.	.160 .105	.113 .055
Mean Canal Diameter for Patients with Slip Ratio below the Mean Slip Ratio (L.1 to L.5)	1.56 1.50 1.47 1.44 1.45	1.48 1.46 1.44 1.40 1.39
Mean Canal Diameter for Patients with Slip Ratio above the Mean Slip Ratio (L.1 to L.5)	1.55 1.52 1.48 1.45 1.46	1.53 1.48 1.44 1.45 1.43

PART 5. Section 16

The patients with degenerative spondylolisthesis show a correlation of .192 between the slip-ratio and canal size at L.5. In addition, those patients with degenerative spondylolisthesis and a slip less than the mean degree of slip have canal measurements considerably less than those with a greater than mean degree of slip ($p < 0.05$) The size of the canal would therefore appear to be a significant factor in the symptomatology of degenerative spondylolisthesis.

Seventy-two patients with spondylolytic spondylolisthesis had a correlation of only .043 between the slip ratio and canal size of the slipping vertebra. In addition, those patients with a slip ratio less than the mean had similar canal measurements to those with a greater slip ratio. The degree of slip and canal size at the level of the slip do not appear to be significant factors in the symptomatology of spondylolytic spondylolisthesis.

In the isthmic type of spondylolisthesis, the canal actually widens at the level of slip as the lamina is left behind when the vertebral body slips forwards. Canal measurements two vertebrae above the level of slip show a correlation of only .082 with the slip ratio, again suggesting that canal size is not a factor in the development of symptoms in this condition. The site of pain must be sought in tissues other than those which can be subjected to compression, irritation or ischaemia within the spinal canal.

PART 5. Section 16 Evidence suggests that the forward slipping in spondylolisthesis occurs before puberty (Wiltse and Jackson 1976, Shenkin and Hash 1976), when the growing neural arch is capable of modifying its shape and size to accommodate its contents.

The attenuated pars should probably be considered a growth phenomenon in the light of the powerful epigenetic influence of the neural contents. When a defect occurs there is probably a failure of the modifying growth process of attenuation, to withstand the high mechanical stress at this site (Troup 1976). It may eventually be shown that when the slip occurs in early infancy, the growth attenuation process is adequate to withstand this stress; a slip later in childhood when the stress will be greater and the ability to modify growth less, may result in a pars defect.

The evidence from ultrasound measurement of the spinal canal suggests that the subject with spondylolytic spondylolisthesis is no more prone to compressive symptoms than the rest of the population. When degenerative spondylolisthesis occurs, it is the subject with the narrow canal who develops symptoms from restricted space.

PART 5. Section 17 MEASUREMENTS FROM PATIENTS ATTENDING A BACK PAIN CLINIC

Ultrasound measurements of the lumbar spinal canal were recorded from 1502 patients attending a 'Back Pain' clinic at Doncaster Royal Infirmary. Many of the patients had a recognisable diagnosis of lower lumbar disc lesion, root entrapment syndrome, neurogenic claudication or pain associated with spondylolisthesis. The series also included patients with ankylosing spondylitis, coccydina and soft tissue contusion. There were many patients in whom no clear diagnosis was made.

TABLE 17. MEASUREMENTS FROM 1502 PATIENTS ATTENDING A BACK PAIN CLINIC

Age Groups	All Back Clinic Patients				Excluding discs, root entrapments, stenotics, spondylolisthesis.			
	% below 10th percentile	% below 10th percentile	Total	Total	% below 10th percentile	% below 10th percentile	Total	Total
	F.	M.	F.	M.	F.	M.	F.	M.
15-18	35%	67%	17	12	33%	57%	17	7
18-30	39%	39%	94	130	39%	40%	74	95
30-50	37%	49%	270	520	33%	41%	172	329
50-65	32%	34%	154	236	34%	34%	50	102
65+	47%	41%	32	37	36%	17%	11	12

Table 17 records the number of patients whose measurements were below the tenth percentile (for their own age group). It is apparent that approximately one patient in three attending the Clinic had a narrow spinal canal below the tenth percentile, irrespective of the cause of their back pain.

PART 5. Section 17. When patients were excluded in whom a firm diagnosis was made, over 30% still had canals below the tenth percentile. The availability of space appears to be important in many patients with so called 'non specific back pain', (Jayson 1979), in both young and older age groups. Some of the young probably have disc symptoms insufficient to produce root irritation, and some of the older patients dural pain (Cyriax 1979), without root involvement.

PART 5.

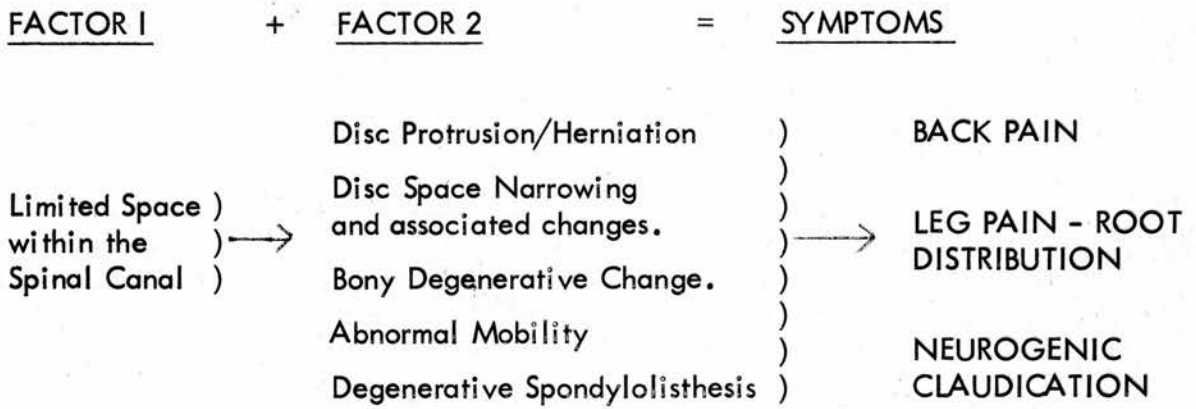
CONCLUSIONS

It has become apparent that the cause of back pain is multifactorial. Lesions which can be identified such as disc derangement, degenerative change and spondylolisthesis, have naturally received the attention of the diagnostician. It is difficult to understand, however, how these lesions can also be present without symptoms, unless it is accepted that back pain is multifactorial. Hult (1954) in the Munkfors investigation, found that 64% of individuals with radiological evidence of disc degeneration, had no back pain. Schmorl and Junghanns in 1959 stated that 15% of the population had degenerative changes of the lumbar spine by middle age, and many had no symptoms. La Rocca and MacNab (1969), found that radiological evidence of degenerative change and disc degeneration in the lumbar spine had no predictive value for an individual. This was confirmed by Gall (1979), and agreed with the work of Bremner and Lawrence (1968) who compared degenerative change and symptoms in a Jamaican and Wensleydale population. The relationship between symptoms and the absence of motion or abnormal mobility was studied by Mensor and Duvall (1959). Absence of movement and abnormal movement, although more common in patients with back pain, was frequently symptomless. There must therefore be factors which in association together are responsible for back pain.

Many authors have suggested that one such factor could be available space within the spinal canal, including Verbiest (1955), Epstein (1960), Ehni (1969), Shenkin and

PART 5.

Hash (1976) and Weinstein (1977). The importance of space within the spinal canal is supported by the ultrasound measurements.



PART 6

THE APPLICATION OF ULTRASOUND MEASUREMENT

OF THE LUMBAR SPINAL CANAL

PART 6. Section 18

CLINICAL APPLICATION OF ULTRASOUND MEASUREMENT

There is merit in measuring the lumbar spinal canal in every patient attending hospital with back pain. It is an investigation which provides useful information, with no discomfort or danger to the patient. It is carried out in a few minutes, and is less expensive than a conventional x-ray.

Frequently, because of difficulty in obtaining accurate measurement, space is a factor that has hitherto been left out of the calculations when considering the cause of a patient's back pain. A recognition of the canal's size, however, assists the clinician reach a diagnosis, and can provide a logical approach to management.

1502 patients attending a Back Pain Clinic had the canal measured by ultrasound. 41% were below the tenth percentile. For many patients lack of space is a factor in the diagnosis. When a patient has back pain in the presence of a narrow canal, two factors probably responsible for his back pain can be presented to him.

- 1) The factor of the narrow canal. He did not choose the shape of his spine and he cannot alter it. The limitation of space makes him vulnerable to symptoms, if the contents of that canal are compromised. Because this factor cannot be altered, he may appreciate the futility of searching for a radical cure, and accept an inherent predisposition to recurrent symptoms.

PART 6. Section 18

- 2) The factor of the precipitating lesion however, is usually associated with mechanical stress, be it an acute or chronic disc lesion, pathology related to disc degeneration, or degenerative spondylolisthesis. This factor can usually be relieved by careful application of principles designed to reduce stress on the spine. Progress will therefore depend on his ability to reduce the mechanical forces on his spine, and a 'Back School' regime (Williams 1977), is readily accepted.

The precipitating lesion can be managed, the narrow canal cannot. It is helpful for both the clinician and the patient to appreciate the difference.

If back pain symptoms are sufficiently severe for surgery to be considered, it would seem prudent to measure the canal. Present methods of measurement have their limitations (Section 1), but ultrasound offers an accurate and relatively simple method. Its value has been discussed in relation to surgery for disc symptoms and for neurogenic claudication. Ultrasound measurement makes it possible for a surgeon to operate on a spine with foreknowledge of the canal size. It should influence his operative management and hopefully improve his results.

PART 6. Section 18 An understanding of the canal size can influence the choice between operative fusion and decompression. It is probably unwise to fuse a spine narrower than 1.3 cm. at the level of fusion or at the level above. Stenosis symptoms can develop after a fusion from bony encroachment into the canal. Alternatively, the added stress at the segment proximal to the fusion may precipitate symptoms at this level from a previously incipient stenosis.

The decision whether to operate and the choice of surgery can be influenced by this simple non-invasive method of measurement.

PART 6. Section 19

PREVENTION OF BACK PAIN

Importance of Prevention

It is especially important to attempt to prevent back pain when it is recognised that our methods of treatment are so ineffective (Sims-Williams et al 1978). Nachemson (1970) has stated that our treatment has not been shown to improve on nature's way of dealing with the problem. Troup et al (1979) in a multi-centric trial of different methods of treatment, identified no method superior to another. The results of surgery are also generally poor (Naylor 1974).

It is difficult to calculate the economic cost of back pain (Dixon 1973), but The Cochrane Report (1979) stated that back pain currently costs the nation £220 million a year in lost output. It costs the National Health Service at least £60 million a year. It is probable that a high economic yield would result from a national policy of pre-employment screening for heavy labouring industry. Radiological methods of screening have proved unreliable in identifying potential back pain sufferers and anthropometric data has given little information about predisposition to back pain (Lawrence 1955, Kelsey 1975, Hirsch 1969). An opportunity of identifying a subject at risk is provided by ultrasound, and being inexpensive and non-invasive, it is an ideal media for screening. The Cochrane Report concluded that control of back pain should be primary prevention. This could be provided by ultrasound.

PART 6. Section 19 Occupations at Risk

It is now possible to identify occupations and activities with a high risk of back pain (Troup 1977). Davis and Stubbs (1976), using a 'radio-pill intra-abdominal measurement technique', found that workers in the construction industry sustaining repeated, frequent high trunk stresses had an increased liability to back injury. Nachemson and Elfstrom (1970), by measuring intra-discal pressures, also demonstrated postures and activities of high risk. Practical experience however, confirms that there are some individuals who can abuse their spines by working for a lifetime in occupations at risk and never experience back pain. It is apparent that there are some individuals at risk, as well as hazardous occupations.

Individuals at Risk

The size of the spinal canal is a highly significant factor in identifying the individual at risk. Ultrasound measurements have shown that several pathological conditions are more likely to produce symptoms of back pain in the presence of a narrow canal. 56% of patients with disc symptoms had canals below the tenth percentile, 69% of patients with neurogenic claudication, 30% of those with root entrapment syndrome, and 32% of patients with degenerative spondylolisthesis. In fact, 41% of all patients attending a Back Pain Clinic had canals below the tenth percentile.

PART 6. Section 19 Ultrasound measurement of the canal offers a practical method of identifying the subject at risk. It has a high degree of accuracy, is non-invasive, relatively cheap and can be completed in a few minutes.

It is not suggested that the size of the spinal canal alone is responsible for back pain. A subject with a narrow canal may avoid back pain, but it is other precipitating factors, often the result of mechanical stress, that compromise the narrow canal and result in symptoms. He should therefore be advised how to minimise the stress on the spine, with an increased understanding of safe lifting techniques, working postures, and recreational activities. Some disabling back pain could be avoided by pre-employment screening, and also the disappointments of the hopeful ballerina, professional gymnast or athlete, whose backs fail them. Some of the complex economic, social and psychological problems of chronic back pain could be prevented.

It is possible that the ideal age for canal measurement as a screening procedure is the early teens, before the career opportunities become restricted. The canal is approaching its adult size, but a longitudinal study would be necessary to determine whether a canal that is narrow at thirteen will remain narrow.

PART 6. Section 19

It may be possible in future to modify the canal growth, but at the present time, the size and shape of the spinal canal must be accepted. Its modification depends upon an understanding of those factors responsible for its growth. Anthropometric measurements suggest factors which may also affect canal growth, and provides an opportunity for further study. If confirmed, and if these factors are environmental, canal growth could be modified.

Prevention at present depends on recognising the subject with the narrow canal, and avoiding lesions which can compromise it.

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MEASUREMENT OF THE SPINAL CANAL BY DIAGNOSTIC ULTRASOUND

R. W. PORTER, MARGARET WICKS, DAVID OTTEWELL

From the Doncaster Royal Infirmary

A method is described of measuring the lumbar spinal canal by pulsed echo ultrasound. It is simple, safe and has a high degree of accuracy. The lumbar canal has been measured in over 800 subjects including 100 mining recruits and fifty nurses between the ages of fifteen and eighteen years. Ultrasound can demonstrate the degree and extent of bony stenosis. It may have value in preventive medicine, identifying the subject at risk.

The size of the spinal canal has attracted increasing interest since Scheslinger and Taveras (1953) and Verbiest (1954, 1955) described some of the effects of the narrow canal. The bony canal, however, is not easy to measure, especially in the clinically most significant midsagittal diameter. Rothman and Simeone (1975) state that it can only be measured accurately by direct measurement at operation. Jones and Thomson (1968) and Eisenstein (1977) have described methods of measuring the midsagittal diameter from a lateral radiograph, but in practice this is not always easy.

Myelography is probably the best method of demonstrating the constraint the canal places upon its contents, but its limitations have been well documented by Ehni (1969), Williams (1975), Jacobson (1976) and McIvor and Kirkaldy-Willis (1976). There can be significant reduction in the cross-sectional area of the canal from exaggeration of the trefoil shape, with an

apparently adequate anteroposterior and lateral diameter. This oblique narrowing may not be recognised by myelography. Sheldon, Sersland and Leborgne (1977) have shown that computed transverse axial tomography will demonstrate this bony encroachment.

This paper presents a method of measuring an oblique sagittal diameter of the lumbar spinal canal by pulsed echo ultrasound. It is simple, safe and has a high degree of accuracy.

METHOD

An oblique diameter of the spinal canal was measured by pulsed ultrasound using a Nuclear Enterprise Ltd Disonograph, a machine now widely used in obstetric diagnosis (Fig. 1). Olive oil was used as a coupling medium between the transducer and the skin. A 1.5 megahertz transducer was placed one centimetre from the midline of the lumbar spine, inclined at 15 degrees to the sagittal plane, and moved longitudinally at the same inclination from the first lumbar vertebra to the fifth (Fig. 2). With repeated movements and slight

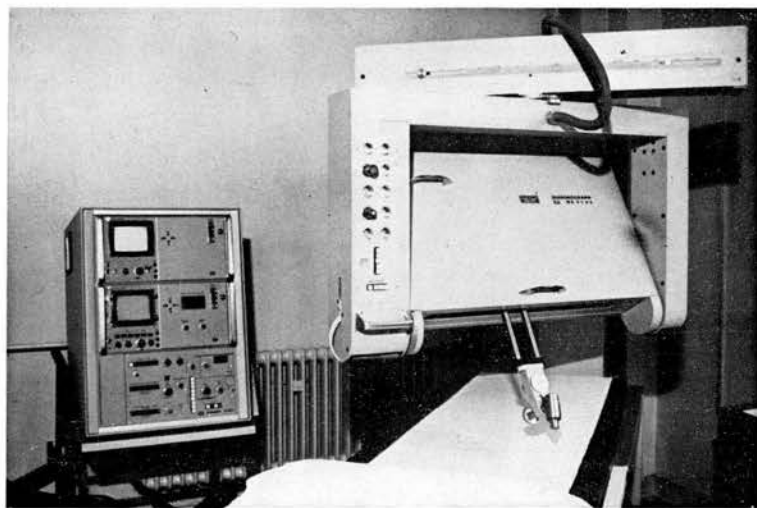


Fig. 1



Fig. 2

Figure 1—Nuclear Enterprise Ltd, Disonograph. Figure 2—Transducer applied to the skin over the lumbar spine.

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Ms Margaret Wicks, Research Assistant

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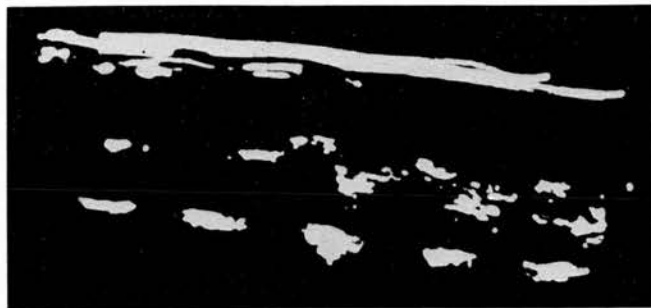


Fig. 3

Two-dimensional display showing echoes reflected from five lumbar vertebrae and laminae.

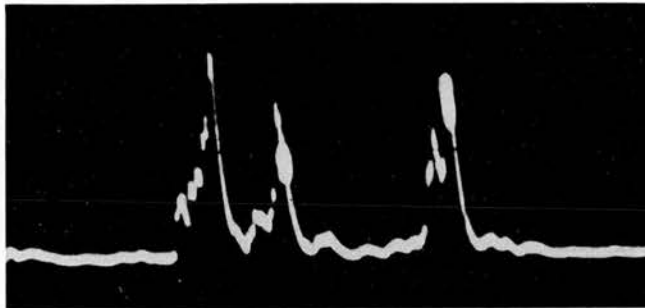


Fig. 4

A-scan display showing three major echoes from the posterior and anterior surfaces of the lamina, and from the posterior surface of the vertebral body.

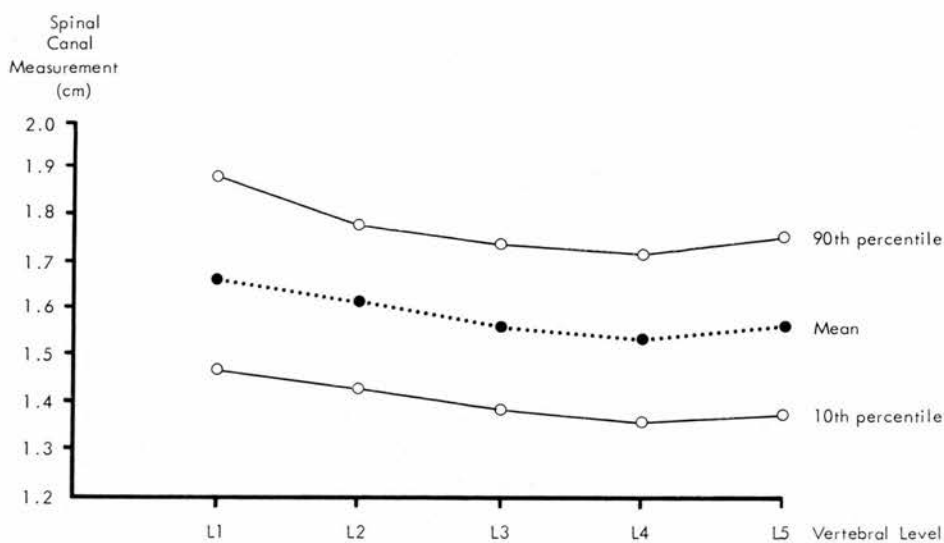


Fig. 5

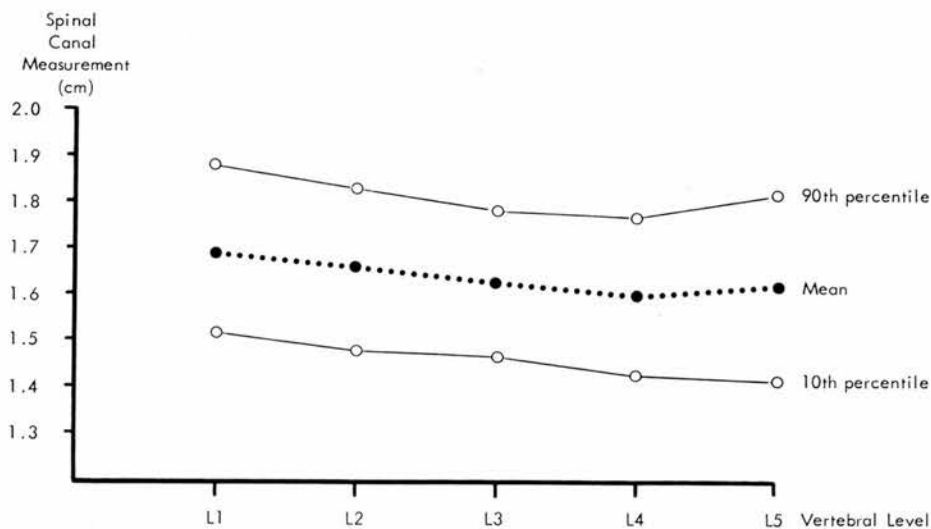


Fig. 6

Figure 5—Mean values and percentiles for 100 young asymptomatic males. Figure 6—Mean values and percentiles for fifty young asymptomatic females.

alteration of the transducer's lateral position, it was possible to obtain echoes reflected from the laminae and from the posterior surfaces of the vertebral bodies as shown in Figure 3. The Diasonograph permits a simultaneous A-scan display of echo amplitudes as a direct function of time, which itself is related to the depth of the reflecting surface below the skin. Three major echoes were demonstrated: from the posterior and the anterior surfaces of the lamina and from the posterior surface of the vertebral body at any one vertebral level (Fig. 4). Slight alteration of the position of the transducer made the amplitudes of these echoes as great as possible and spurious echoes were removed by electronic filtering. The time interval between the second and third echoes from the canal boundaries is related to the distance between the reflecting surfaces, and is measurable in millimetres on a digital read-out. This is facilitated by electronic calipers positioned at the apex of the second and third echoes on the A-scan, and simultaneously displayed on the B-scan identifying the vertebral level of the echoes. The identity of the reflecting surfaces of the three major echoes was confirmed by immersing cadaveric vertebrae in saline, ultrasound and direct measurements being identical.

RESULTS

The lumbar canal has been measured in over 800 subjects, including 100 male mining recruits between fifteen and eighteen years old, and fifty nurses of the same age. The degree of accuracy of measurement of the oblique sagittal diameter of the lumbar canal is shown by the fact that the inter-observer and intra-observer error is only 0.02 centimetre. Difficulty in measuring the canal occurs only in the very obese and, of course, after posterior spinal fusion.

The mean values, and the tenth and ninetieth percentiles for the 100 miners and fifty nurses are demonstrated diagrammatically in Figures 5 and 6. In the oblique sagittal diameter the lumbar canal is widest at the first lumbar level, narrowest at the fourth, and tends to widen again at the fifth level. The mean values of the canals of the young nurses are slightly wider than those of the young miners. Measurements from both the right and left sides of the lumbar spinal canal have been recorded from sixty patients with low backache with or without sciatica. The mean and standard deviation of the differences for each level are shown in Table I.

DISCUSSION

Ultrasonic energy transmitted into the tissues is partially reflected by the boundaries between different structures. This reflected energy is detected as an echo, and the pulsed emission enables the same transducer both to transmit the ultrasound and to receive the returning echoes. Consequently, echoes are received only when reflected from the surfaces at approximately 90 degrees to the axis of the beam. The reflected angle must lie within the solid angle defined by the width of the face of the transducer and the depth of the reflecting surface below the skin. However, the microscopic irregularity of the bony surface ensures that some echoes are received from the vertebral lamina and the posterior surface of the vertebral body, even though the surfaces macroscopically appear oblique to the direction of the incident beam of ultrasound.

Three major echoes on the A-scan are obtained over an extremely narrow band when the transducer is inclined at 15 degrees to the sagittal plane. This band corresponds to the acoustic "window" in the lamina, through which the sound can be transmitted and

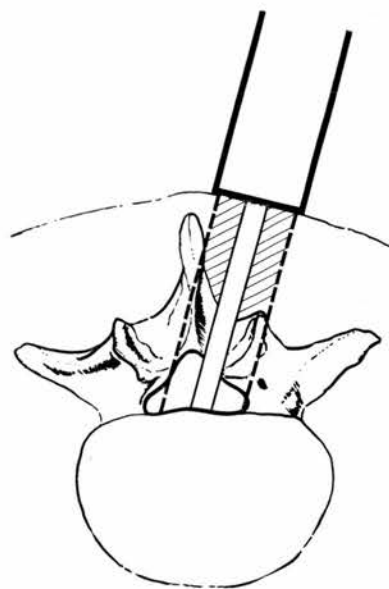


Fig. 7

Diagrammatic representation of part of a two-centimetre beam of ultrasound penetrating the lamina "window".

received. The echoes are lost if the transducer is moved either medially, because of the high absorption of sound by the bony spinous process, or laterally, from absorption by the facet joints and thickened lateral lamina. The "window" of thin bone is entirely covered by the two-centimetre diameter beam of ultrasound and is constant for each individual vertebra (Fig. 7). This probably explains the high degree of reproducibility of the results.

Table I. Differences between right and left oblique sagittal diameters for sixty subjects with backache, with or without sciatica

	Mean difference (centimetres)	Standard deviation of difference
L1	0.035	0.041
L2	0.042	0.045
L3	0.046	0.062
L4	0.073	0.113
L5	0.055	0.074

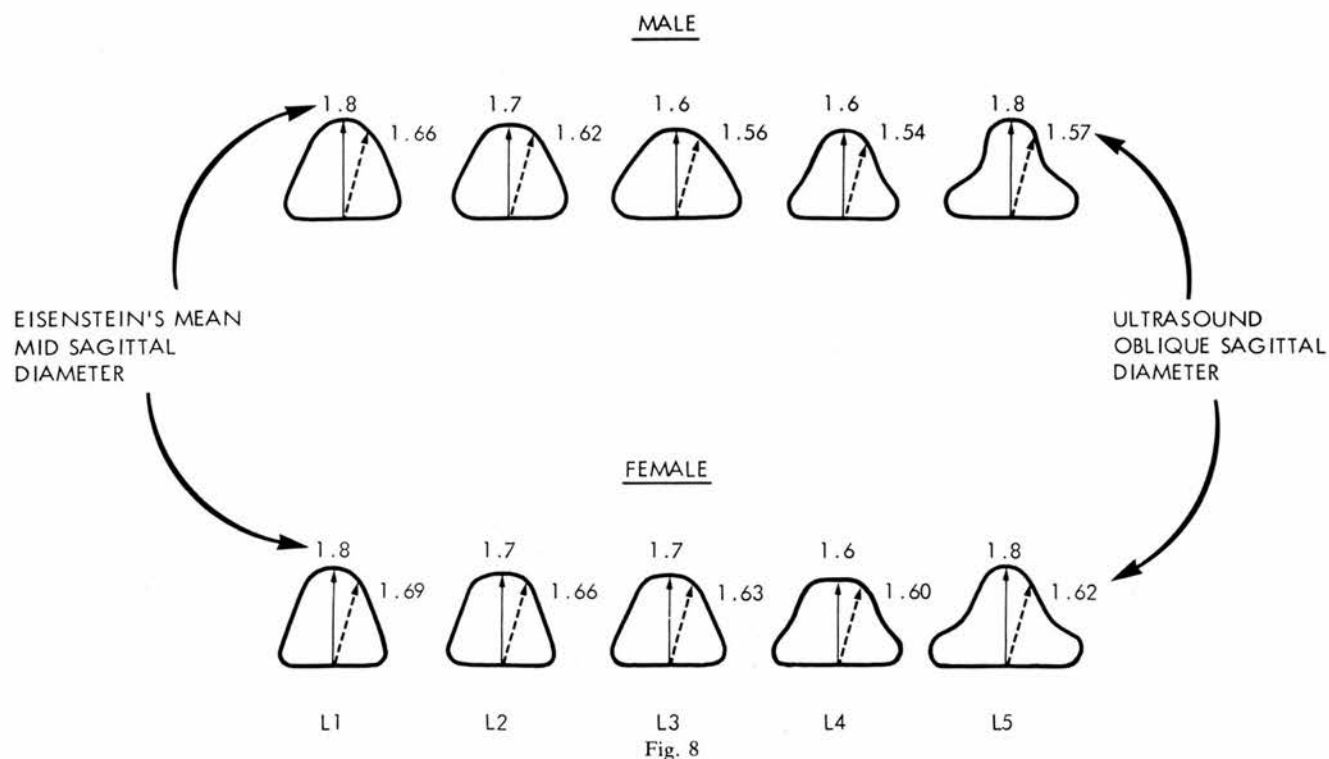
The mean oblique sagittal diameter measured by ultrasound is similar to the midsagittal diameter measurements reported by Eisenstein (1977) (Fig. 8). It is understandable that the oblique measurements are less than the midsagittal. The difference is most marked

at the fifth lumbar vertebra where the canal can be trefoil in shape. This will significantly affect our measurements because of the obliquity of the diameter recorded by ultrasound. The mean values for the female canal were found to be slightly greater than those for the male.

Ultrasound measurement of the spinal canal has several clinical implications. Bony stenosis responsible for symptoms of claudication can be identified in degree

adequate. Transverse axial tomography will demonstrate this encroachment, but ultrasound offers the advantages of a non-invasive technique that permits accurate measurement. In addition, measurement at each lumbar level helps the surgeon decide the segmental extent of necessary decompression.

The simplicity, safety and accuracy of ultrasound measurement provides opportunity for preventive



Comparison between mean oblique sagittal diameters measured by ultrasound and Eisenstein's mean midsagittal diameters.

and extent. It is fortuitous that ultrasound measures an oblique diameter that is most affected in stenosis when laminar hypertrophy exaggerates the trefoil shape. This bony encroachment may not be detected by myelography when the midsagittal and coronal diameters are

medicine if it can be shown that a narrow canal increases the risk of disabling symptoms from pathological changes in the disc and from degenerative changes. Young subjects at risk could be identified easily and advised against hazardous occupations and recreations.

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THE SPINAL CANAL IN SYMPTOMATIC LUMBAR DISC LESIONS

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From the Doncaster Royal Infirmary

The oblique sagittal diameter of the lumbar spinal canal was measured by diagnostic ultrasound in seventy-three patients with symptomatic disc lesions, and compared with measurements from 200 asymptomatic subjects. Results suggest that the available space in the spinal canal is highly significant in the symptomatology of disc lesions, and in the patient's response to treatment.

Following the description by Mixter and Barr (1934) of the syndrome of ruptured lumbar intervertebral disc, clinicians have shown more interest in the size of the lesion than in the available space in the spinal canal. It is increasingly recognised, however, that a disc protrusion or herniation can compromise an already narrow canal (Williams 1975; Choudhury and Taylor 1977; McCulloch 1977; Verbiest 1977). The relative importance of the size of the spinal canal in the symptomatology of the acute lumbar disc lesion has not been established because of difficulty in obtaining accurate measurement. Ultrasound measurement of the oblique sagittal diameter of the lumbar canal can now provide the opportunity to assess the significance of canal diameter in the presence of disc symptoms.

METHOD

The oblique sagittal diameter of the lumbar spinal canal was measured by ultrasound in patients with symptomatic disc lesions. They had to satisfy three or more of the criteria described by McCulloch (1977): unilateral leg pain in a typical sciatic root distribution, including discomfort below the knee; specific neurological symptoms incriminating a single nerve; limitation of straight leg raising by at least 50 per cent of normal; at least two neurological changes of muscle wasting, muscle weakness, sensory change, or hyporeflexia; and myelographic evidence of disc protrusion.

Measurements were obtained from seventy-three patients with a mean age of thirty-nine years (plus or minus eleven years). Forty-six were men and twenty-seven women. Twenty-eight patients settled with bed rest at home. Of the forty-five admitted for inpatient traction, twenty-one failed to improve and were treated surgically. The measurements were compared with those of 200 asymptomatic subjects, 100 mining recruits between fifteen and eighteen years old, and 100 nursing cadets of the same age.

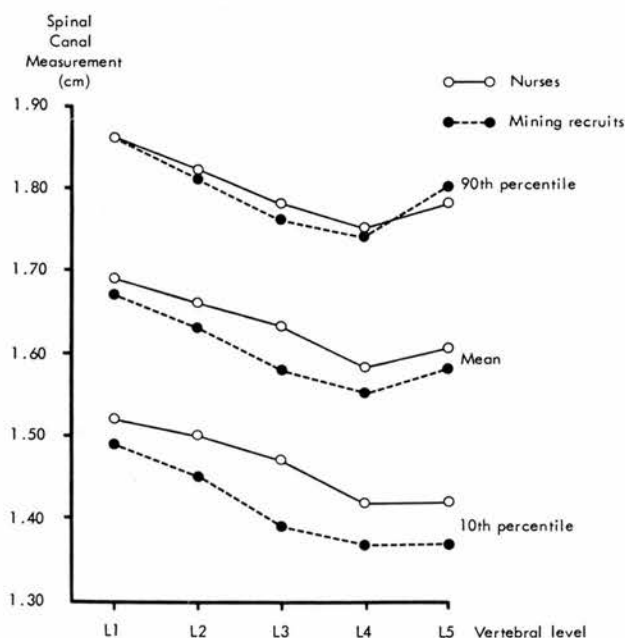


Fig. 1

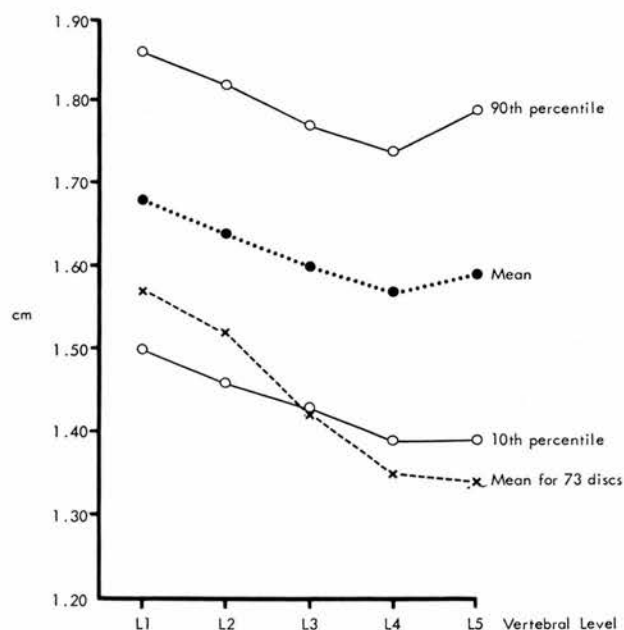


Fig. 2

Figure 1—Mean values and percentiles of oblique sagittal diameter from 100 miners and 100 nurses. Figure 2—Comparison between mean measurements from seventy-three patients with disc symptoms and 200 asymptomatic subjects.

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RESULTS

The measurements of the spinal canals of the 200 asymptomatic subjects are shown diagrammatically in Figure 1, with mean values, and tenth and ninetieth percentiles for miners and nurses at each lumbar level.

The size of the canal at the fifth lumbar level was not related to the findings at operation. Nine patients with sequestered discs had mean diameters of 1.28 centimetres compared with 1.27 centimetres for nine patients with disc protrusions (Table II).

Table I. Mean spinal canal measurements in centimetres

	200 asymptomatic subjects	73 symptomatic disc lesions	28 discs settled at home	24 discs settled with inpatient traction	21 discs treated surgically
L1	1.68	1.57	1.60	1.52	1.58
L2	1.64	1.52	1.56	1.47	1.52
L3	1.60	1.42	1.45	1.41	1.42
L4	1.57	1.35	1.38	1.32	1.33
L5	1.57	1.34	1.37	1.35	1.27

The mean values for the seventy-three patients with disc lesions are compared with the asymptomatic subjects in Figure 2, and the measurements at the fifth lumbar level are compared with the percentiles of the asymptomatic subjects in Figure 3. Fifty-five per cent were below the fifth percentile, and 68 per cent were below the tenth percentile.

There was a relationship between the size of the canal and the response to treatment. Twenty-eight

DISCUSSION

The available space in the spinal canal is highly significant in the symptomatology of disc lesions. The fact that 55 per cent of patients with disabling disc symptoms had canal measurements below the fifth percentile of asymptomatic subjects suggests that many patients with wider canals escape root involvement in the presence of disc prolapse. It is the patients with measurements less than 1.4 centimetres at the fourth and fifth lumbar levels who are at risk. The probability of failure to respond to treatment is also related to the size of the canal. The narrowest canals were recorded in the patients who required surgical treatment.

Table II. Mean spinal canal measurements in centimetres

	9 sequestered discs	9 disc protrusions
L1	1.62	1.60
L2	1.55	1.54
L3	1.45	1.41
L4	1.41	1.27
L5	1.28	1.27

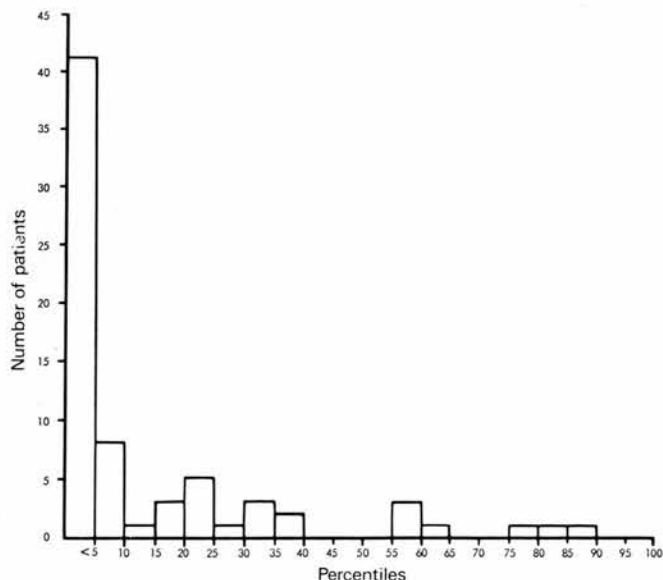


Fig. 3

Measurements from seventy-three patients with disc symptoms compared with percentiles of 200 asymptomatic subjects.

patients whose symptoms settled at home had a mean diameter of 1.37 centimetres at the fifth lumbar level. This same mean diameter was 1.32 centimetres for forty-five patients requiring admission, and 1.27 centimetres for the twenty-one patients treated by operation (Table I).

Lumbar nerve roots will be most vulnerable to compression in a narrow canal of trefoil shape. Eisenstein (1977) recorded the trefoil shape at the fifth lumbar level in 15 per cent of spines he examined, and concluded that this was a developmental variant rather than the result of degenerative change. The pattern of measurement throughout the lumbar spine suggests that many of the canals we have measured in patients with disc symptoms are narrow canals of trefoil shape (Fig. 4). The mean oblique measurement recorded by ultrasound decreased throughout the lumbar spine in

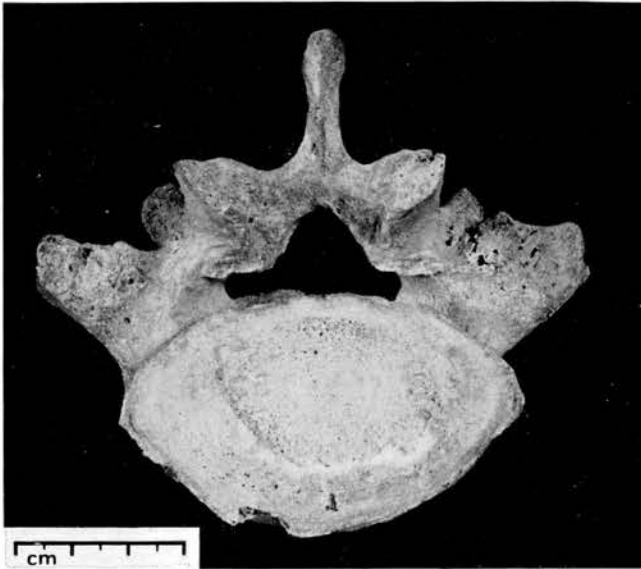


Fig. 4

Trefoil L5 spinal canal. Nerve roots would be vulnerable to compression in the presence of a disc lesion.

seventy-three patients with disc symptoms and was narrowest at the fifth level, whilst the mean measurements of 200 asymptomatic subjects were narrowest at the fourth level, widening again at the fifth. The trefoil shape most significantly affects the oblique sagittal diameter, and when this mean measurement is smaller at the fifth level than at the fourth, it probably indicates a high incidence of the trefoil shape.

No correlation was found between the size of the canal at the fifth level and examination of the disc at

operation. We had anticipated that the canals would be wider in patients with herniations than in those with smaller disc protrusions, but this was not confirmed in this small series.

The high incidence of narrowing in the presence of disc symptoms is probably not generally recognised, and may account for some of the poor results of operation. It is difficult to appreciate the dimensions of the spinal canal when it is examined through the usual limited exposure. Naylor (1974) records a continuation of some symptoms in 62 per cent of patients after operations for disc prolapse, and Gurdjian *et al.* (1961) in 71 per cent. Verbiest (1977) explored and measured the canal at several levels with a "Stenosimeter". He reported surgical failures due to unrecognised stenosis in the presence of disc protrusions.

Measurement of the spinal canal before operation offers a more rational approach to surgical treatment. In the presence of a 1.1 centimetre canal and a small protrusion, it would be unreasonable to enucleate the disc through a fenestration and risk subsequent stenotic symptoms. Decompression would be a more reasonable procedure and might perhaps be necessary at more than one level. The larger sequestration in a wider canal can readily be treated by excision of the disc alone.

The risk of developing disabling symptoms from disc protrusion is inversely related to the size of the spinal canal. It is now possible in adolescence to identify subjects at risk and to offer vocational counselling and the benefits of ergonomics to this selected group. It would be economically relevant, and offer hope of reducing a major cause of morbidity in adults.

We are grateful to Mrs M. Platts and Mrs J. Reynolds for the typescript, and to the National Coal Board for its financial assistance.

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1979 Volvo Award for Basic Science

Backache and the Lumbar Spinal Canal

R. W. PORTER, FRCS, FRCSE, C. HIBBERT, BSc, and
P. WELLMAN, BSc

This paper records measurement of the lumbar spinal canal by diagnostic ultrasound in more than 700 subjects from early infancy until the age of 65 years. It demonstrates the range of canal size in a South Yorkshire population. The canal is relatively wide in children, reaches a maximum diameter in the late teens, and reduces slightly by late adult life. This does not appear to be related to occupation. Comparisons are made with more than 700 patients with symptoms of back pain, especially patients with disabling disc symptoms, root entrapment syndrome, and neurogenic claudication. The size of the central canal is particularly significant in patients who have neurogenic claudication and disc symptoms. It is less significant in root entrapment syndrome. [Key words: low-back pain, spinal canal size, ultrasound]

THE RELATION between back pain and the size of the spinal canal has not been established because of the difficulty of obtaining accurate measurement. The midsagittal diameter is difficult to measure by conventional radiographic methods, especially at the lower lumbar levels where the canal's posterior boundary is indistinct. Jones and Thompson⁴ and Eisenstein² have demonstrated methods for its identification, but the methods are not always easy to apply. Verbiest¹⁰ has measured the canal at operation with a "stenosimeter," and Rothman and Simone⁸ state that the canal can be measured accurately only by this direct measurement. Computed axial tomography will demonstrate bony encroachment.^{3,9} It offers an opportunity to identify variations in the size and shape of the canal.

Pulsed echo ultrasound can provide a repeatable measurement of the spinal canal in the 15° oblique plane.⁷ This paper describes the measurements obtained

by ultrasound from a random sample of more than 700 subjects between infancy and the age of 65 years, and compares their results with more than 700 patients suffering from back pain.

METHOD

Measurements were obtained by ultrasound from two groups of young people between 15 and 21 years of age; the first were 188 male recruits to the coal mining industry, and the second, 102 female nurses. The canal was measured in 150 children from the second to the 18th year. These children had neither backache nor known pathologic conditions of the spine. Most had visited a clinic for treatment of upper limb fractures. Measurements were recorded from three groups of subjects between 50 and 65 years of age. Two hundred were underground miners who had received a financial incentive to attend for measurement. They represented half the underground labor force in that age group at one colliery. Eighty were male sedentary workers, mostly doctors, solicitors, or office workers. Fifty-two were female nurses. Comparisons were made between these groups and patients who had back pain.

Lower Lumbar Disc Lesion

One hundred fifty-four patients under the age of 45 years were considered for lower lumbar disc lesions.

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with a lower lumbar disc lesion. They fulfilled two of the following three criteria: 1) unilateral leg pain in a nerve root distribution, extending below the knee, and worse in the leg than in the back; 2) straight leg raising less than 50°; and 3) two of four abnormal neurologic signs: diminished reflex, sensory loss, muscle weakness, muscle wasting.

Clinic Patients

Measurements were obtained from a consecutive series of patients attending an orthopaedic clinic, 165 under the age of 30 years, and 242 between 50 and 65 years old. They were unselected apart from the fact that they complained of pain in the lower back, the leg, or both.

Root Entrapment Syndrome

Seventy-eight patients over the age of 45 were considered to have symptoms of root entrapment. They had unilateral leg pain in a nerve root distribution from the buttock to the foot. Back pain was frequently absent or mild. The leg pain was severe and constant, often making the patient pace the floor at night. Unlike the pain of younger patients with disc symptoms, this pain was not relieved by recumbency. Abnormal signs were few. Back extension was frequently limited, and there was often slight lower lumbar tenderness. Straight leg raising was usually full or only slightly reduced, and neurologic signs were normal.

Neurogenic Claudication

The canal was measured in 138 patients who had classic symptoms of neurogenic claudication. Symptoms involved both legs in a generalized rather than in a root distribution and were aggravated by walking and relieved by rest. Abnormal signs were few, and the peripheral circulation was normal.

RESULTS

Canal measurement for the 15- to 21-year-old miner and nurses are recorded in Figure 1. The spinal canal in children is relatively large (Figure 2). In infancy the mean oblique diameter is 1.38 cm, which steadily increases to 1.58 cm at puberty (Figures 3 and 4). The measurements in the three older groups of miners, sedentary workers, and nurses between the ages of 50 and 65, are more than 1 mm less than the young adults, the sedentary workers having narrower spines than the miners (Figure 5).

There were 154 patients with disabling disc symptoms. Their average age was 37 years, and 66% were male (Table 1). Their mean measurements are compared with the tenth percentile for young people in Figure 6. Fifty six percent are below the tenth percentile at L5 (Figure 7).

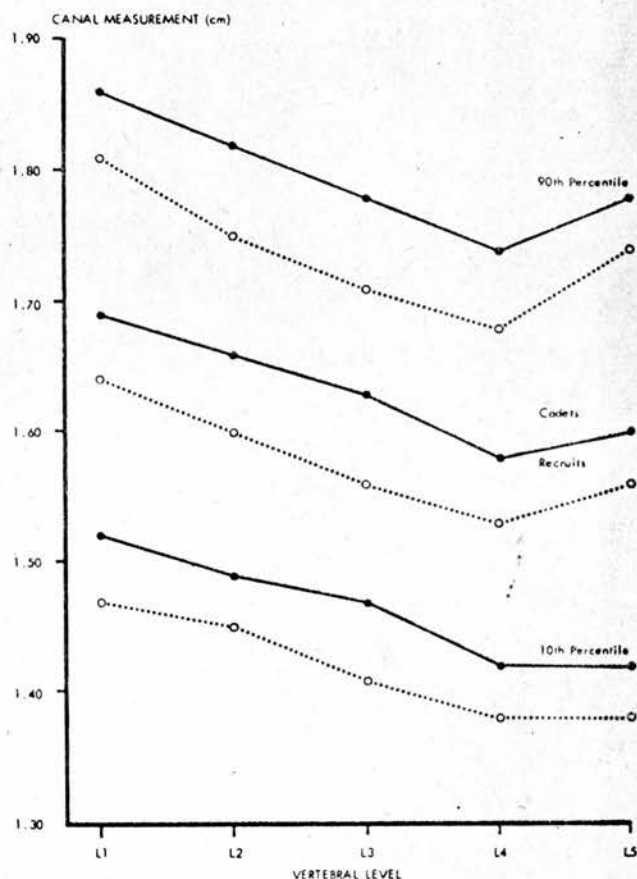


Fig 1. Fifteen-degree oblique sagittal diameter of the lumbar spinal canal, mean and percentiles, for 188 male mining recruits and 102 female nurses between 15 and 21 years of age.

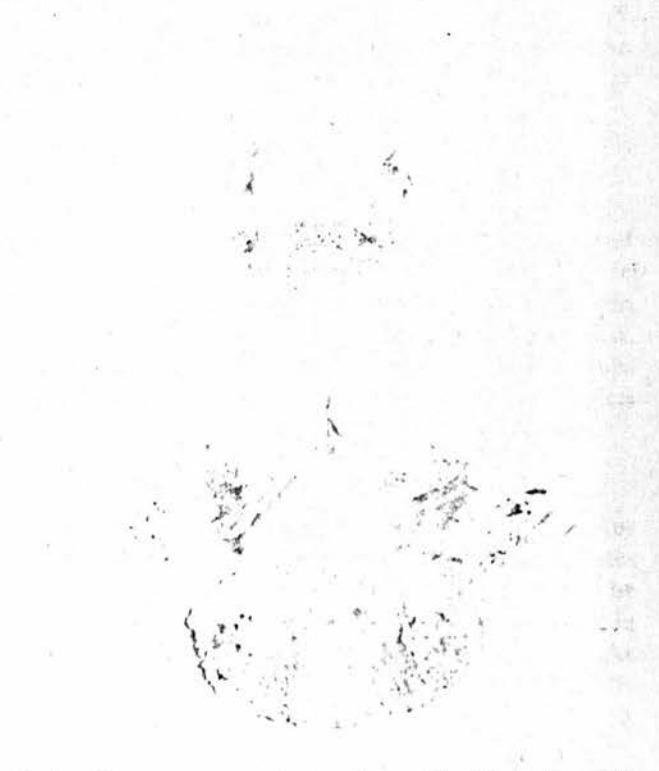


Fig 2. Photograph comparing canal size of the fifth lumbar vertebra of a 3-year-old child and that of an adult.

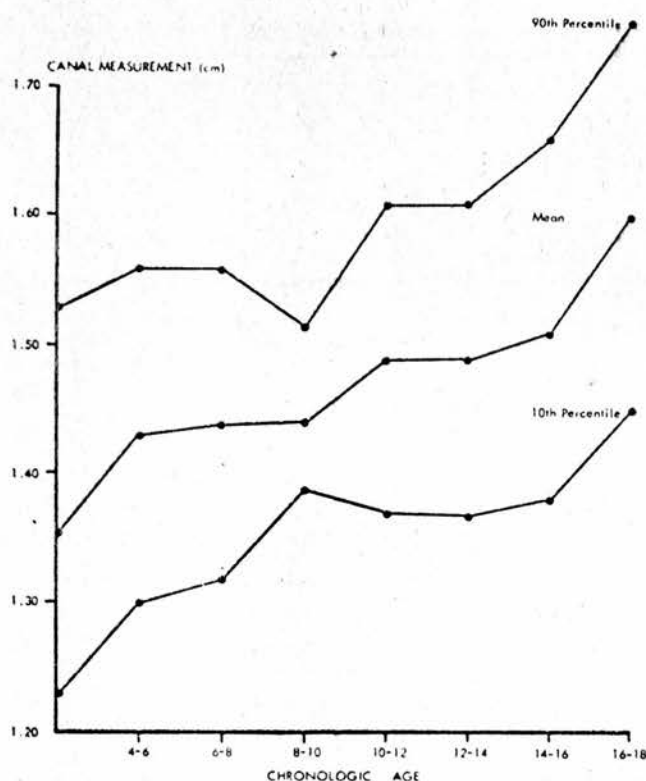


Fig 3. Mean value of canal diameter at L5 in 150 children.

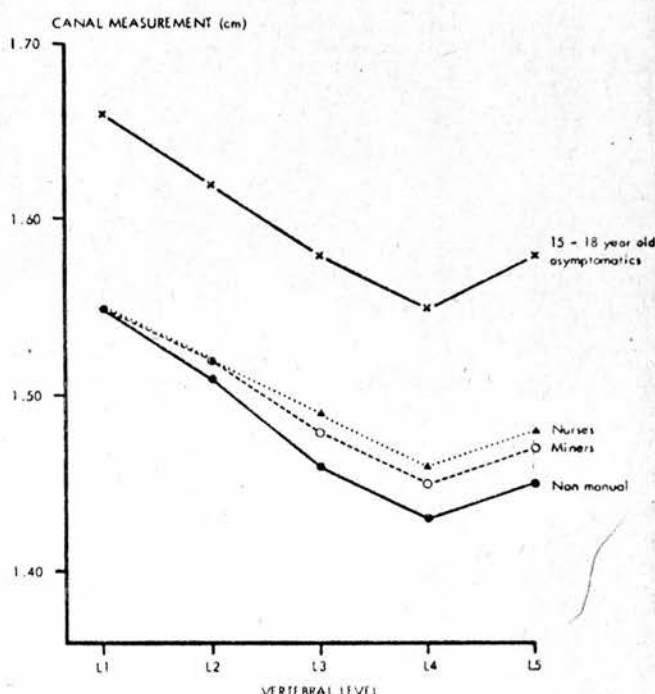
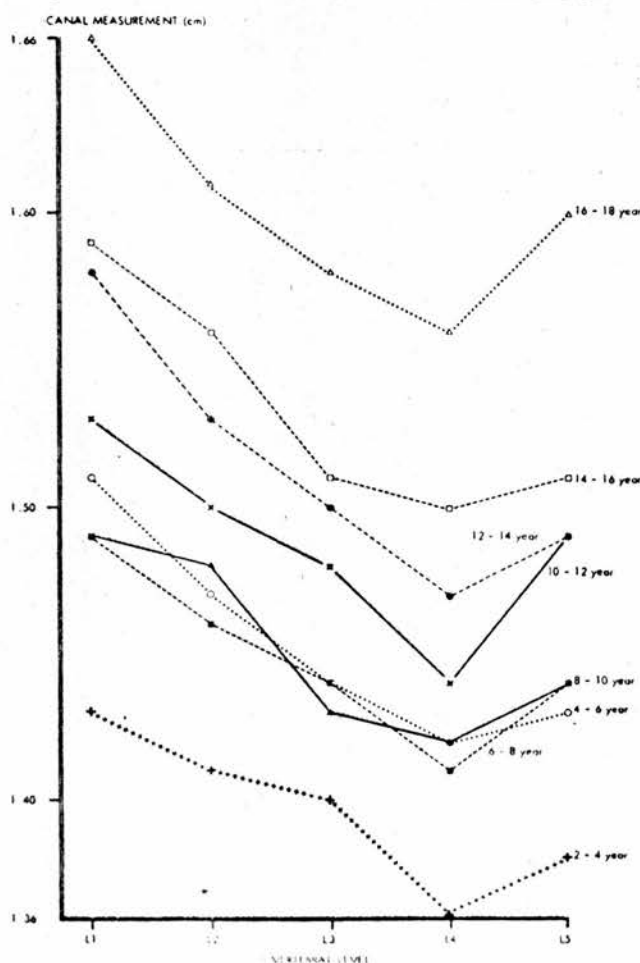


Fig 5. Mean canal size for three groups between the ages of 50 and 65 years (miners, male sedentary workers, and nurses), compared with 15- to 21-year-old subjects.

trapment syndrome and an average age of 56 years are compared with the mean and tenth percentile of the older subjects (Figures 8 and 9, Table 1). Only 30% are below the tenth percentile.

One hundred thirty-eight patients who had a history of neurogenic claudication had an average age of 49 years. Seventy percent had measurements below the tenth percentile for the 50- to 65-year-old subjects (Figures 10 and 11, Table 1).

Measurements from the two groups of clinic patients, unselected apart from the fact that they complained of back pain, show that 50% of those between 15 and 30 years old are below the tenth percentile, while 45% of those between 50 and 65 years old are below the tenth percentile for their own age groups (Table 1). The mean measurement for these two groups of patients is similar. Comparisons are made between the two clinic groups and the percentiles at L5 for randomly selected subjects of the same age (Figure 12).

DISCUSSION

We have previously recorded canal measurements for young nurses and miners. In this larger series the figures remain the same. The canal of women was found to be wider than that of men in the young adults and also in the 52 older nurses compared with the 280 men of the same age. The difference is very small but is statistically significant in the young adults ($P < 0.05$). A larger spinal canal would be more advantageous during pregnancy when the spine is subjected to altered mechanical forces and increased ligamentous laxity. The canal of

Table 1. Patients With Low-Back Pain Whose Spinal Canals Were Measured by Diagnostic Ultrasound

Pathologic condition	Number of patients	Mean age (yr)	Male (%)	Below 10th percentile (%)	Age category
Disc lesion	154	36.7	65.6	56	Young adults
Root entrapment	78	56.2	51.3	30	Older adults
Neurogenic claudication	138	48.8	73.2	70	Older adults
Clinic patients aged 15-30 yr	165	24.5	60.0	50	Young adults
Clinic patients aged 50-65 yr	242	56.0	59.3	45	Older adults

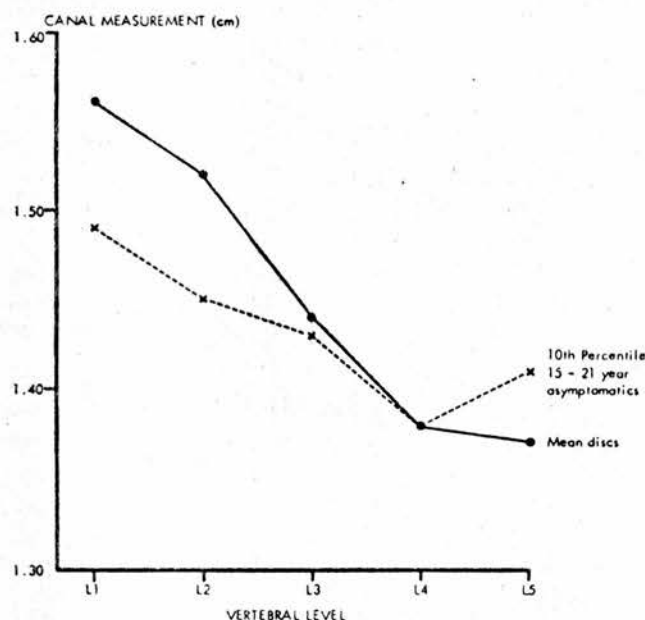


Fig 6. Mean measurements for 154 patients with disc symptoms, compared with tenth percentile of 15- to 21-year-old patients.

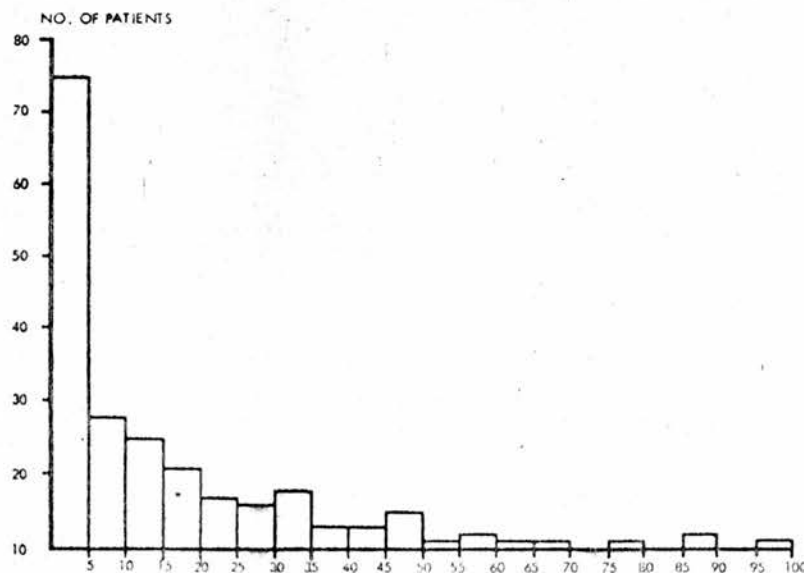


Fig 7. Histogram of canal size at L5 for 154 patients with disc symptoms, compared with percentiles for 15- to 21-year-old subjects.

women may contain more extradural fat than that of men.

The canal is relatively large in infancy. Our measurements are probably artificially high in the very young children, because the thin neural arch increases the lamina "window" through which ultrasound enters the spinal canal. It may reflect the midsagittal rather than the 15° oblique diameter, because both laminae and the apex of the neural arch are included in the "window." A midline scan is possible in the infant, while the thickened spinous process absorbs the ultrasound in the older child and adult. The failure of measurements to increase in the first decade (Figure 3) is therefore probably more apparent than real.

The pattern of measurements from L1 to L5 remains the same throughout growth, with the canal decreasing in size from L1 to L4 and increasing again at L5 (Figure 4).

The relative position of the cord rising within the growing spine does not appear to affect the canal size.

Measurements from the miners, sedentary workers, and nurses over the age of 50 years shows that the 15° oblique diameter reduces with age. It is possible that the lamina "window" through which ultrasound enters the

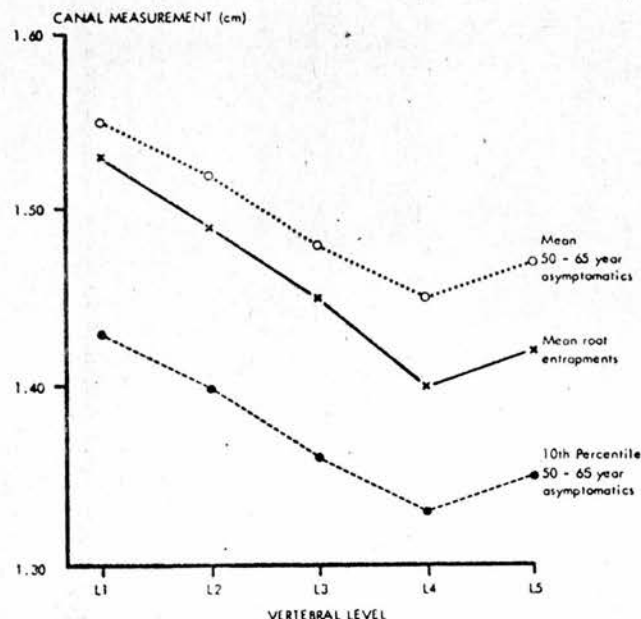


Fig 8. Mean measurements for 78 patients with root entrapment syndrome, compared with mean and tenth percentile of 50- to 65-year-old patients.

canal becomes smaller with age as a result of bony hypertrophy. The second and third echoes which are reflected through the window are certainly most clearly visualized in the young adult. Decrease in the size of the window, however, would not explain a reduction in canal measurement. If the window decreases, it is probably a uniform reduction around the periphery of the window which would not affect the measurement at all.

Subperiosteal ossification at the attachment of the ligamentum flavum could explain this age-related narrowing.

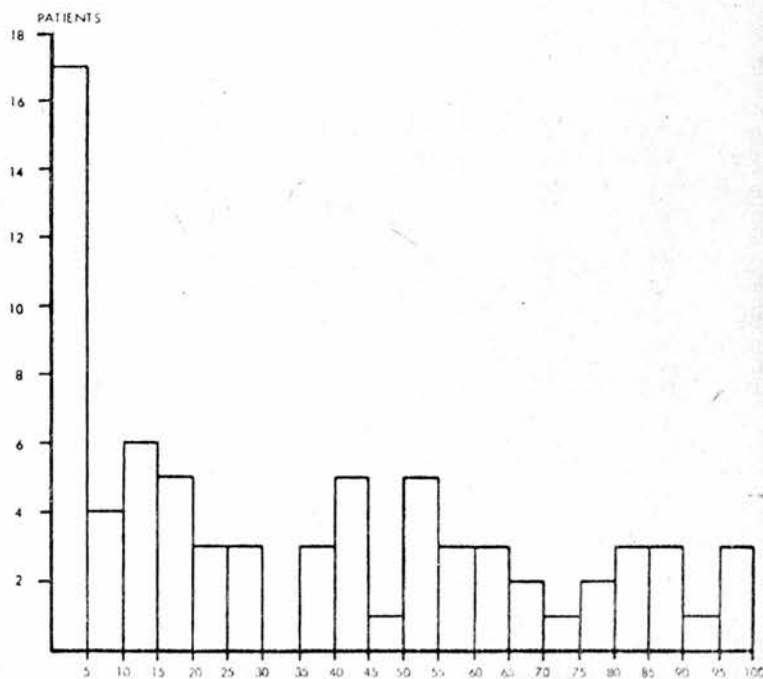
The size of the canal does not appear to be related to occupation. Men who have worked for three and four decades underground, some of whom were involved in very heavy work in confined spaces in early adult life prior to mechanization of the coal industry, have canals slightly wider than men who have been in sedentary occupations. It is possible that the miners have selected themselves out of the industry and that those with troublesome narrow spines have taken other employment. If demanding work significantly affected the diameter of the spinal canal, however, it would probably have been demonstrated in this study.

The failure of occupation to affect the size of the canal suggests that the narrow canal should be considered to be developmental rather than degenerative. Degenerative change might produce localized encroachment, but would not affect the general shape and size of the canal.

Ultrasound measurements have shown that the majority of patients who have disabling disc symptoms have a narrow canal in addition to disc pathology. Fifty-six percent of 154 patients with disc symptoms were below the tenth percentile for the young people (Table 1). The figures are similar when considering all the patients between 15 and 30 years of age attending a hospital clinic with back pain, suggesting that many of these may have had a disc lesion compromising a narrow canal and yet have avoided serious root signs.

The pathologic condition responsible for root entrap-

Fig 9. Histogram of canal size at L5 for 78 patients with root entrapment syndrome, compared with percentiles for 50- to 65-year-old patients.



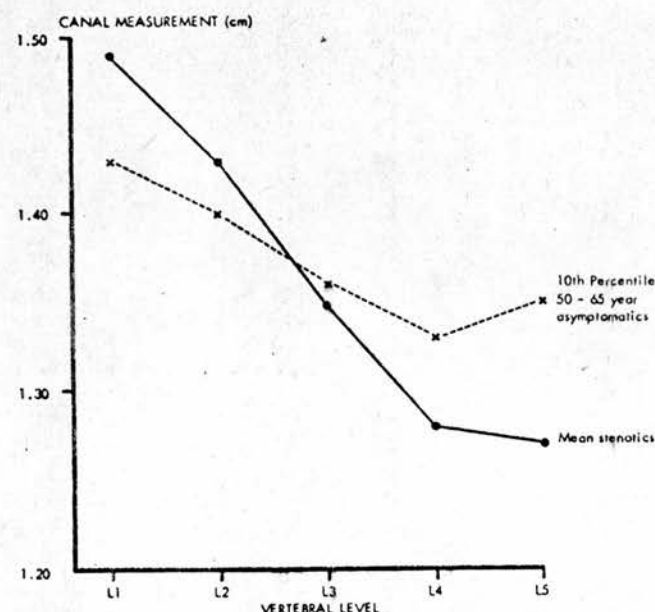


Fig 10. Mean measurements for 138 patients with neurogenic claudication, compared with tenth percentile for 50- to 65-year-old patients.

ment syndrome is probably within the root canal.⁵ The central canal only is measured by ultrasound, but 30% of 78 patients diagnosed as having root entrapment had canals below the tenth percentile of the 50 to 65-year-old miners, nurses, and sedentary workers. A subject whose central canal measurement is below the tenth percentile is four times more likely than the rest of the population to have root entrapment symptoms. This increases to 11 times in the presence of a disc lesion. It is probable that a pathologic condition in the root canal is more likely to cause symptoms if the central canal is also narrow, though many patients with root entrapment do have adequate central canal measurement.

The relative importance of soft tissue and bony narrowing in the causation of neurogenic claudication has been in dispute. Measurements suggest that the size of

the central canal is highly significant in the majority of patients who have claudication. Seventy percent are below the tenth percentile (Table 1). Not all subjects who have a narrow canal develop claudication, however. It is probable that soft-tissue thickening, bony encroachment, and "instability" are the added factors responsible for symptoms.

Almost half (46%) of the 138 patients who had claudication were miners. There is no evidence to suggest that the central canal is narrowed by heavy underground work, but additional factors such as previous disc pathology, vertebral bars associated with degenerative change, facet joint degeneration, thickened ligaments, and "instability" probably compromise the canal that is already narrow.

If the size of the central spinal canal is an important factor responsible for compression of the cauda equina, the shape of the canal must also be significant. The nerve root will be particularly vulnerable to compression when the canal is trefoil. There is a probability that the canal is trefoil at L5 if the ultrasound measurement at L5 is equal to or less than that at L4. It is significant that the mean values and percentiles are greater at L5 than at L4 in the children, young miners, and nurses and in the older subjects. This pattern is not observed in the patients who have disc lesion or stenosis. It suggests that the trefoil shape, in addition to the canal diameter, is symptomatically important.

Ultrasound measurements indicate that the available space in the central spinal canal is a factor, but not the only factor, in the causation of many types of disabling back pain. The canal size is highly significant in the presence of disc pathology and in a patient who has neurogenic claudication, and in most young patients who attend a hospital clinic with back pain. It is a relevant factor for many older patients attending hospital with back pain. It is less significant in patients suffering from root entrapment syndrome.

The development of many of the structural types of severe back pain is probably explained by the following diagram:

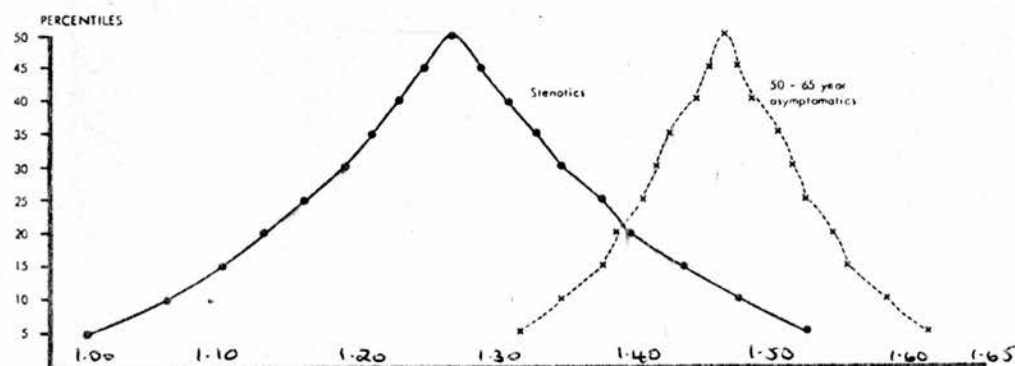
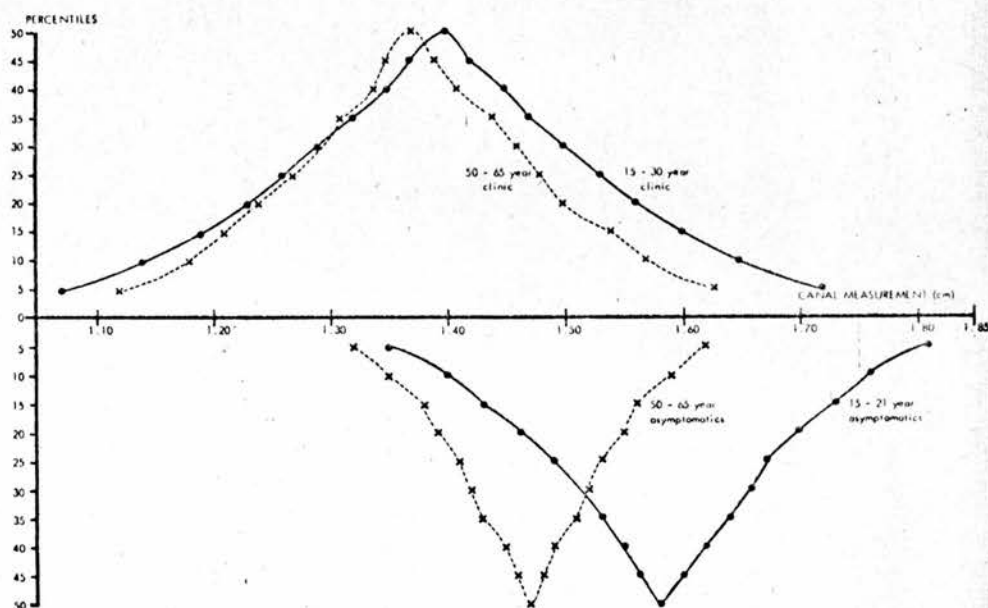


Fig 11. Comparison of canal measurement percentiles at L5 between 138 patients with neurogenic claudication and the 50- to 65-year-old subjects.

Fig 12. Comparisons of canal measurement percentiles at L5 between two clinic groups with back pain and randomly selected subjects of the same age.



Disc lesion
Mechanical force
Degenerative change
"Instability"

BACK PAIN
plus NARROW CANAL
ROOT SYMPTOMS

Some of the mechanical forces responsible for pathologic conditions of the spine have been demonstrated by Nachemson and Elfstrom⁶ and Davis and Stubbs.¹ They are theoretically preventable. Advice should be offered to that section of the population at greatest risk.

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